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HYDROGEOCHEMICAL INVESTIGATION OF REACTIVE TAILINGS AT THE WAITE AMULET TAILINGS SITE, NORANDA, QUEBEC - 1985 PROGRAM

Final Report

by

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SUMMARY

Noranda Inc. initiated a five-year research program in 1985 undertaken by Noranda Research Centre to conduct a hydrogeochemical investigation of the reactive Waite Amulet tailings area near Noranda, Quebec. This study is part of the national Reactive Tailings Study (RATS) Program. A jointly funded Noranda-CANMET $100,000 study for 1985 consisted of a preliminary site reconnaissance and drilling program to provide a baseline indication of the underlying geologic materials and their variations, the tailings depth, water table, mineralogy, pore water chemistry, pore water hydraulic conductivity and direction of flow. Bacterial activity was also assessed.

The evaluation of the hydrogeology and geochemistry of the Waite Amulet tailings area will provide an indication of where the acid generation is occurring and its regulating factors. This will assist in developing control techniques which will eliminate the need for perpetual maintenance and treatment of acid water from reactive tailings area.

The 1985 field program indicated that the Waite Amulet tailings, which varies in thickness from 2 to 15 m, is underlain by moderately regular clay with thickness varying from 2 to 20 m. The water table is near surface in the northern section and up to 5.5 m below surface in the southern section. Hydraulic conductivities range from 9×10^{-7} to 1.4×10^{-3} cm/s. Porewater horizontal velocities within the tailings range from 0.4 cm/y to 5 m/y. Velocities across the dam face are up to 35 m/y.

Below the water table, pH is generally above pH 6, and in the unsaturated zone, the pH ranges from 3 to 6. Thiobacillus ferrooxidans are present only above the water table and there was a minimal count of sulphate-reducing bacteria below the water table.

The 1986 program will: resolve the hydrogeological uncertainties concerning the site; evaluate the geochemistry in the unsaturated zone and dam face; assess oxidation control options for 1987-1989.

1. INTRODUCTION

The Reactive Tailings Study (RATS) Program is jointly funded by Canada Centre for Mineral and Energy Technology (CANMET), the mining industry and prospectively several of the provinces.

The objective of the RATS program([1]) is to produce an inventory of practical techniques which will enable the impact of acid generating tailings (reactive tailings) to be sufficiently reduced so as to allow their ultimate abandonment without the need for on-going treatment or maintenance.

A number of studies([2]) were proposed within the context of the RATS program by INCO, Falconbridge, Cominco and Noranda. Noranda submitted a proposal([3]) (Appendix A) to undertake a hydrogeochemical investigation of the reactive tailings at the Waite Amulet Tailings site near Noranda, Quebec, to develop a better understanding of the hydrogeochemical processes and control mechanisms which occur in an acid generating tailings area.

The RATS program sanctioned the Waite Amulet study, and a contract was issued to Noranda Research on 26 June 1985 in the amount of $50,000 with equivalent funds provided by Noranda Inc., for the first phase 1985/86 activity.

1.1 Study Objectives

The overall objective of the RATS program is to eliminate the need for perpetual maintenance and water treatment for reactive tailings areas. Achievement of this objective will be via the

development of a better understanding of the biohydrogeochemical processes and controlling mechanisms. Based on this understanding, improved long-term tailings management practices can be developed.

To achieve these objectives, a five-year research program of the existing hydrogeology, geochemistry and bacterial activity was recommended to assess the biohydrogeochemical processes and controlling mechanisms.

1.2 Scope

The 1985 Waite Amulet field program, the first year of a five-year field program, consists of a preliminary site reconnaissance and drilling program. Figure 1 illustrates the project schedule and cash flow. Table I details cost estimates for the five-year program.

As part of the 1985 field program, a geophysical survey was conducted to assess the tailings depth and underlying geologic structure. The tailings hydrogeology was assessed with the installation of a piezometer network. The tailings porewater geochemistry in the saturated zone was assessed via the piezometer installations.

Core samples were collected to determine the mineralogy and engineering properties of the tailings solids. The core samples were also analyzed for iron oxidizing and sulphate reducing bacteria.

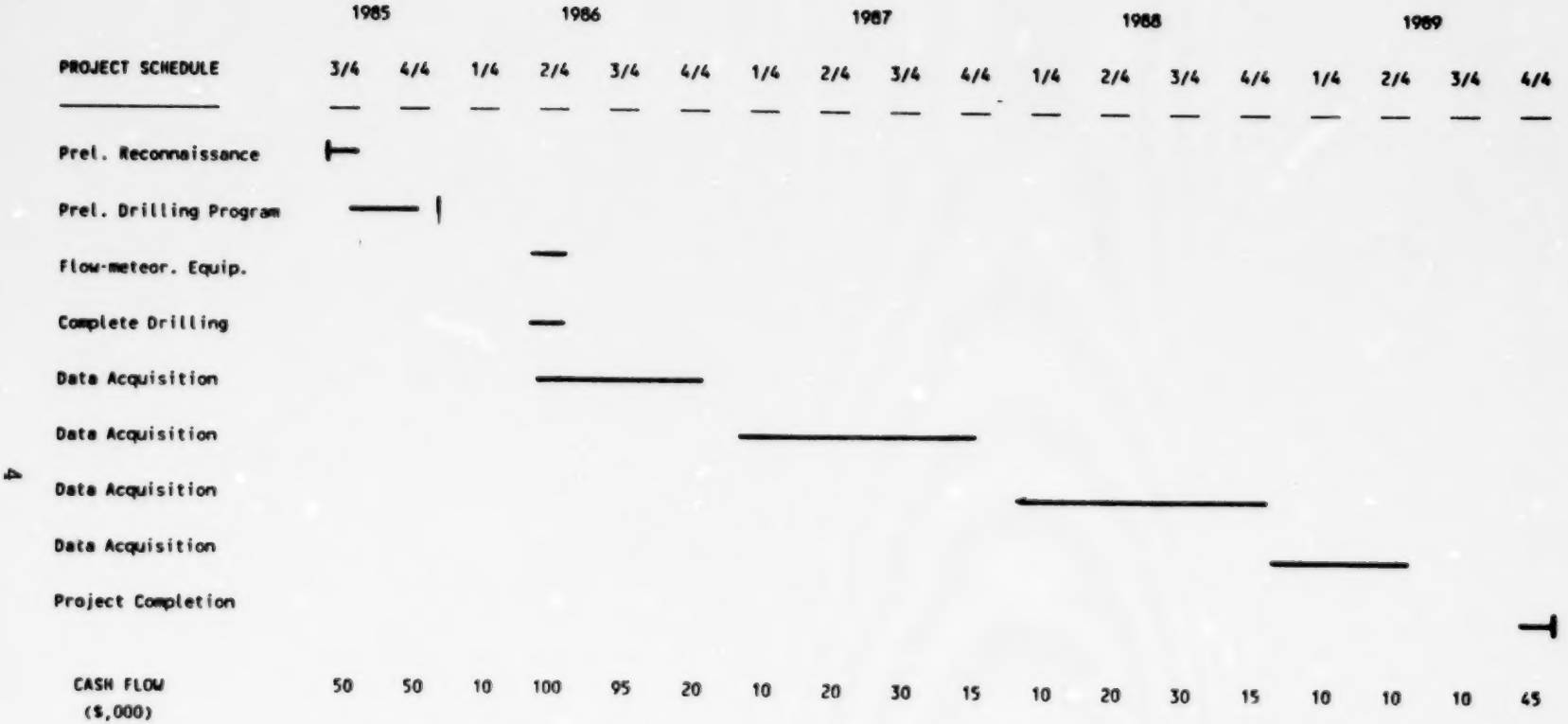

Figure 1 - Project Schedule and Cash Flow

TABLE I

DETAILED COST ESTIMATES

	Labour	Material	Contract	Total
1985 Program				
Preliminary Reconnaissance				
- water table evaluation	15,000	5,000		20,000
- surveying			5,000	5,000
- water analysis			5,000	5,000
				$ 30,000
Preliminary Drilling Program				
- site supervision	15,000			15,000
- drilling, core sampling	5,000		46,000	51,000
- surveying	-	4,000		4,000
				$ 70,000
			1985 Total:	$100,000
1986 Program				
Flow recorder-meterological equipment				
- site supervision	10,000			10,000
- climateclogical station		15,000	5,000	20,000
- flow recorders/samplers		40,000	5,000	45,000
				$ 75,000

Note: Labour includes lodgings and transportation for Noranda Research and site supervision by Noranda Inc., Horne Division, Noranda, P.C

TABLE I (Cont'd)

DETAILED COST ESTIMATES

	Labour	Material	Contract	Total
Complete drilling program				
- site supervision	10,000			10,000
- drilling core sampling			30,000	30,000
- surveying			5,000	5,000
- additional flow recorders	5,000	20,000	5,000	30,000
				$ 75,000
Data Acquisition				
- data collection	10,000		25,000	35,000
- water analysis			25,000	25,000
- analysis and reporting	15,000			15,000
				$ 75,000
		1986 Total:		$225,000
1987 Program				
- analysis and reporting	30,000			30,000
- data collection			25,000	25,000
- water analysis			20,000	20,000
		1987 Total:		$ 75,000
1988 Program				
- analysis and reporting	30,000			30,000
- data collection			25,000	25,000
- water analysis			20,000	20,000
		1988 Total:		$ 75,000
1989 Program				
- analysis and reporting	50,000			50,000
- data collection			15,000	15,000
- water analysis			10,000	10,000
		1989 Total:		$ 75,000

1.3 History of the Waite Amulet

The Waite Amulet tailings area, which is situated approximately 20 km north of Noranda (Figure 2) ceased operation in 1962 leaving 5.9 million tonnes of reactive sulphide tailings in an elevated 41 hectare dam and tailings spills in a lower area. Acid seepage and tailings surface runoff are collected in an acid water reservoir. A computer controlled high density sludge lime neutralization plant utilizes lime to neutralize precipitate and remove metals to provide an acceptable effluent.

1.3.1 History of Mining Operations([4])

In August of 1928, mining of the Amulet ore began with ore averaging 8.1% Cu, 4.9% Zn and 2 oz/ton Ag was shipped to the Noranda Horne Smelter operations. In 1929, the 272 tonnes/day Amulet mill was constructed. In 1933, the Waite-Ackerman-Montgomery and Amulet shares were incorporated into Waite Amulet Mines Ltd. With the war demand for zinc, a new 1088 tonnes/day mill went into production to treat 816 tonnes/day of Cu-Zn ore from the Amulet Dufault and 272 tonnes/day from the Waite orebodies. A 300 tonnes/day mill extension went into operation in 1943. The mill then treated 907 tonnes/day of Lower "A" ore, 408 tonnes/day of Waite ore and 317 tonnes/day from the Amulet "C" orebody. The original Waite mine terminated in 1948. The Amulet "C" orebody was exhausted in 1951.

The mill capacity was increased in 1955 to treat 907 tonnes/day of West MacDonald ore. Waite Amulet production was reduced

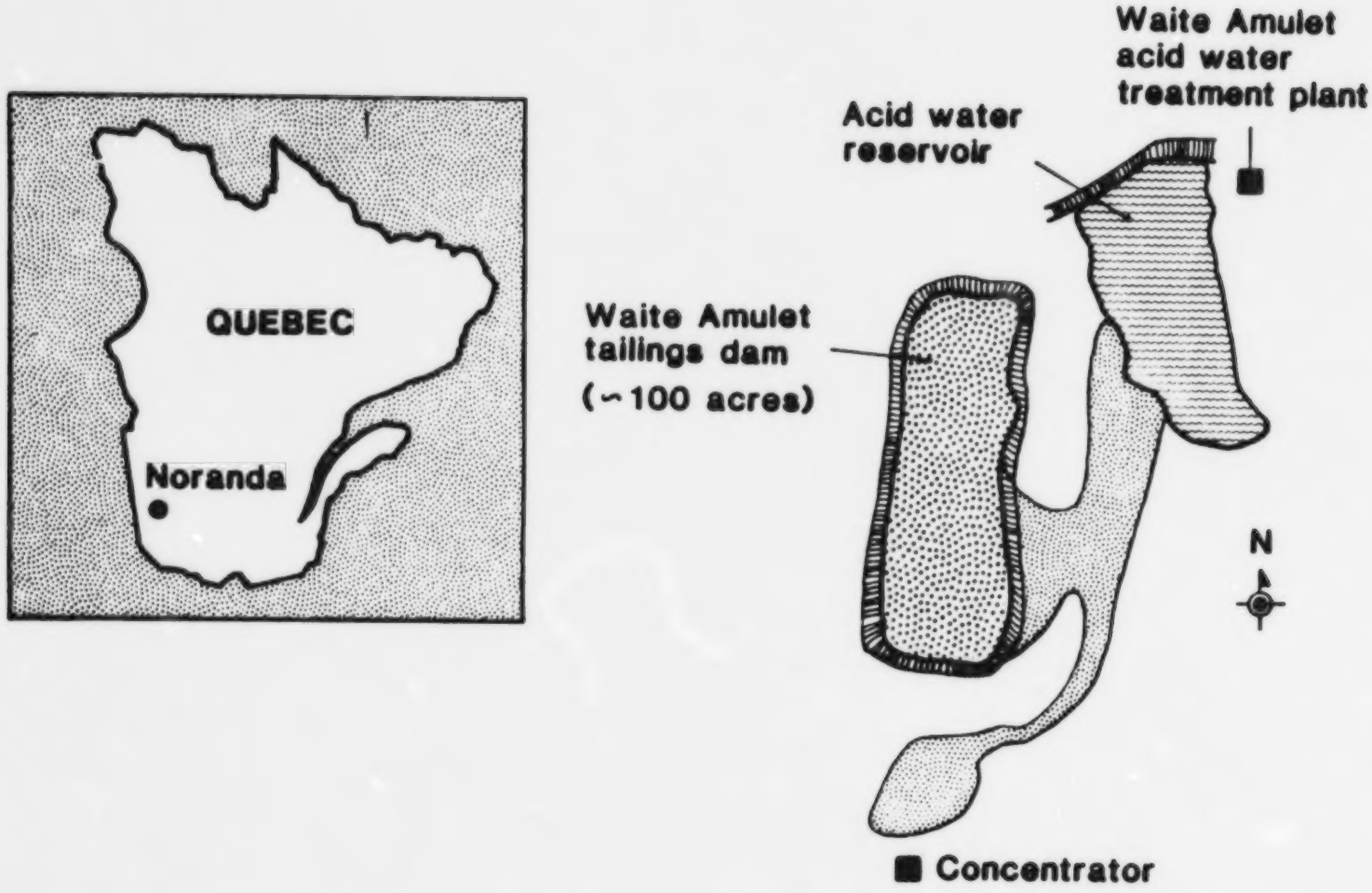

Figure 2 - Waite Amulet Tailings Area

to 907 tonnes/day.

A pyrite flotation circuit was installed to produce a pyrite concentrate.

An aerial tramway was used to transport the West Macdonald ore situated on the east side of Lake Dufault, to the Waite Amulet mill. The West Macdonald operation ceased in 1958. The only remaining orebody, the Amulet Dufault Lower "A", was exhausted in October 1962.

In total, ten orebodies were milled and the tailings disposed of in the Waite Amulet mill tailings area. Approximately 8.74 million tonnes were milled from the nine Waite Amulet and Amulet Dufault orebodies of which 2.65 million came from the Waite-Ackerman-Montgomery property, 1.17 million from the Amulet and 4.63 million from the Lower "A" Amulet orebodies. The West Macdonald orebody contributed approximately 0.81 million tonnes.

1.3.2 History of Milling Operations([5])

The 1814 tonnes/day mill treated 91 tonnes/day of West Macdonald ore and 907 tonnes/day of Waite Amulet and Amulet Dufault ores. The Waite ores were approximately 60% sulphides (chalcopyrite, marmatite, pyrite and pyrrhotite) and the West Macdonald ore consisted of 95% sulphides, mainly pyrite and marmatite with minor amounts of chalcopyrite, pyrrhotite and galena.

The Waite gangue consisted of diabase and feldspar porphyry.

Gangue from the West Macdonald ore consisted of lamprophyre and rhyolite.

The Waite Amulet mill flowsheet is illustrated in Figure 3. The Waite Amulet and West Macdonald grades and reagent consumption are detailed in Table II.

1.3.3 History of the Tailings Area

No available literature discusses the placement and operation of the 41 hectare main tailings dam. The tailings were gravity fed from the mill via a wood stave pipeline and trestle. The method of tailings dam construction may have been with original waste rock starter dams with subsequent lift construction using coarser spigotted tailings. The tailings were end spilled during winter operation in the central north and south sections.

The area between the concentrator and main tailings dam contains varying depths of tailings (1-2 m). Placement details are not known, but in the early 1920-1930's, tailings were probably disposed in this lower region; and later, spills from the wood stave pipeline probably contributed.

1.3.4 Tailings Reclamation

The Horne Division's first full-scale revegetation attempts in the late 1960's were unsuccessful due to the high acidity of the tailings and the revegetation techniques utilized. These problems were eventually solved with the help of researchers from the University of Guelph.

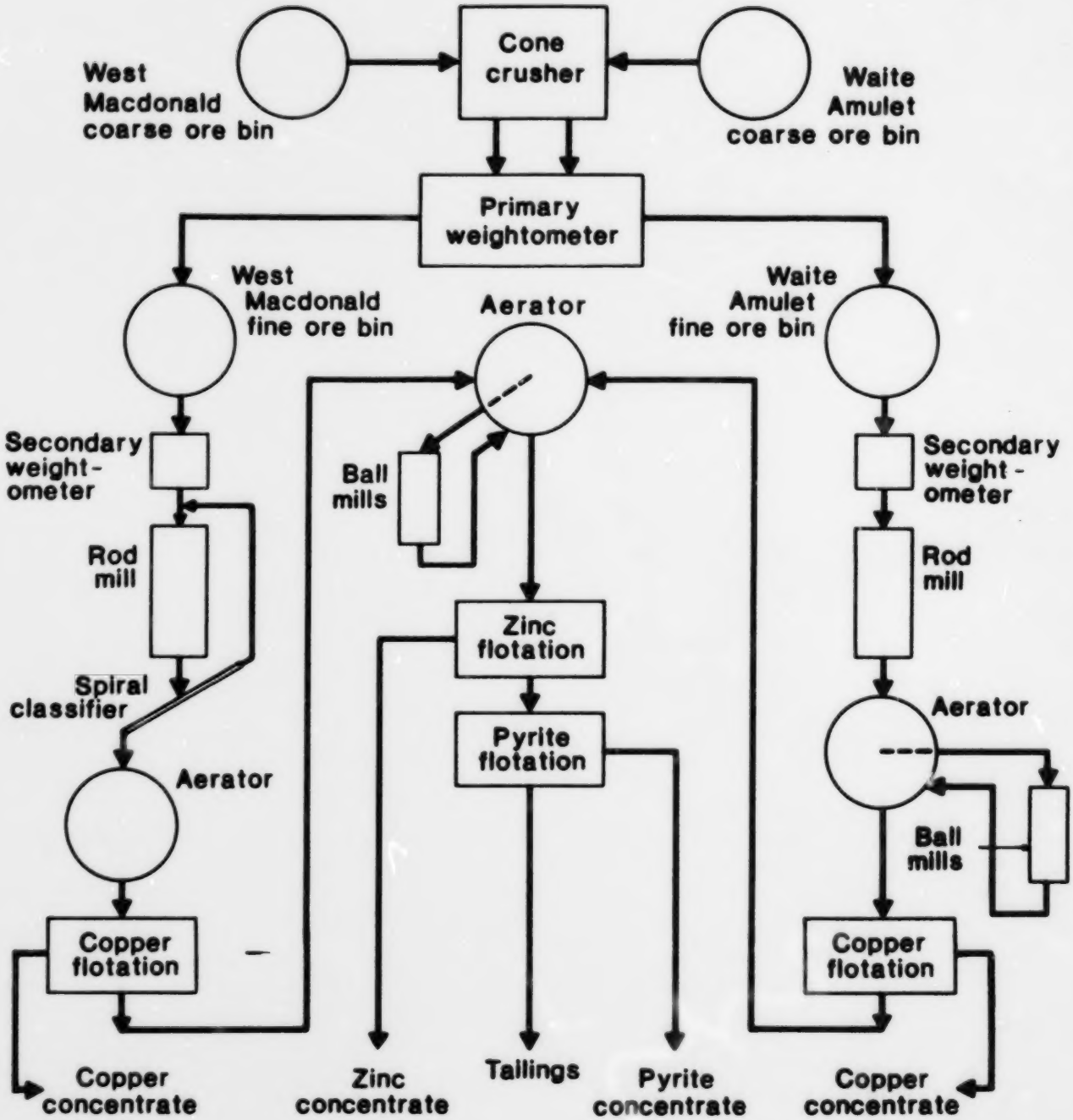

Figure 3 - Waite Amulet Mill Flowsheet (1956)

TABLE II

WAITE AMULET AND WEST MACDONALD METALLURGY (1956) AND REAGENTS([5])

METALLURGY

	Cu %	Zn %	S %	Au oz/ton	Ag oz/ton
Waite Amulet ore	3.89	3.95	18.91	0.041	8.93
Recoveries (%)	94.49			65.41	65.33
West Macdonald ore	0.13	2.41	46.47	0.027	0.82
Recoveries (%)	7.62			7.53	6.47
Combined zinc recovery (%)		85.6			
Pyrite recovery (%)			83.2		
Pyrite tailings	0.16	0.26	12.82		

REAGENTS

	Waite Amulet Cu Flotation	West Macdonald Cu-Ag-Au Flotation	Zinc Flotation	Pyrite Flotation
Sodium sulphide (lb/ton)	1.086	0.302		
NaCN	0.028	0.007	1.870	
Soda Ash	2.336	1.650		
Aerofloat 242	0.066	0.013		
Z-5	0.074			
Frother 73	0.073	0.012	0.065	0.017
Aerofloat 208		0.005	0.093	
$Ca(OH)_2$			0.329	
$CuSO_4$			1.437	
$(NH_4)_2SO_4$			0.185	
Aerofloat 343				0.162

The majority of the main sulphide tailings dam was revegetated in 1978 and 1979. The pH of the tailings surface was neutralized with 44 tonnes/hectare of agricultural limestone. Up to 2.2 tonnes per acre of fertilizer was used because these tailings are devoid of any nutrients. Birdsfoot trefoil and a companion crop of creeping red fescue were planted.

2. METHODS OF INVESTIGATION

The following section reviews the methods of investigation for the geophysical survey, tailings hydrogeology, tailings porewater geochemistry, tailings mineralogy and presence of bacteria. Appendix B and C detail the methods of investigation excluding the mineralogy. The monthly progress reports are found in Appendix D.

2.1 Geophysical Survey

A geophysical survey was conducted to determine the depth of tailings and underlying clay, variation in the bedrock and conductivity variations in the tailings. Two parameters were measured - seismic velocity and electric conductivity. The seismic refraction survey details the vertical variations in geologic layers by monitoring the change in shock wave velocity along geologic boundaries. The electromagnetic (EM) survey was conducted by inducing an electromagnetic field into the ground. Secondary fields are created which are a function of the electrical properties of the ground.

Direct current resistivity soundings measure the variation in resistivity of the ground as an electrical current passes through. Resistivity varies according to grain size and water content. Altering the spacing between the electrodes increases the depth of penetration to differentiate geologic units.

The geophysical work was undertaken by Mr. P. Pehme, Waterloo Geophysics Ltd., and details of theory and application are found in Appendix C. The effectiveness of resistivity and EM surveys cannot be fully assessed as the mineralogical parameters are not completely analyzed yet.

2.2 Tailings Hydrogeology

A total of 53 piezometers were installed in 22 nests in the main tailings dam as illustrated in Figure 4. Piezometers were a modified Casagrande drive-point type developed at the University of Waterloo. Preliminary reconnaissance of the site dictated the installation of 30 piezometers. These were installed by pounding with a steel mandrel or using a percussion drill, with advances of 1.5 m lengths of 3 cm ID schedule 40 PVC pipe. The evaluation of the hydraulic gradients, pH and electrical conductance determined the location for the second phase piezometer nest. The remaining piezometers were installed by percussion drill and with the use of a track-mounted CME 75 drill rig. Water levels were monitored prior to pumping out the wells to assess hydraulic conductivity using the Hvorslev rising head test.

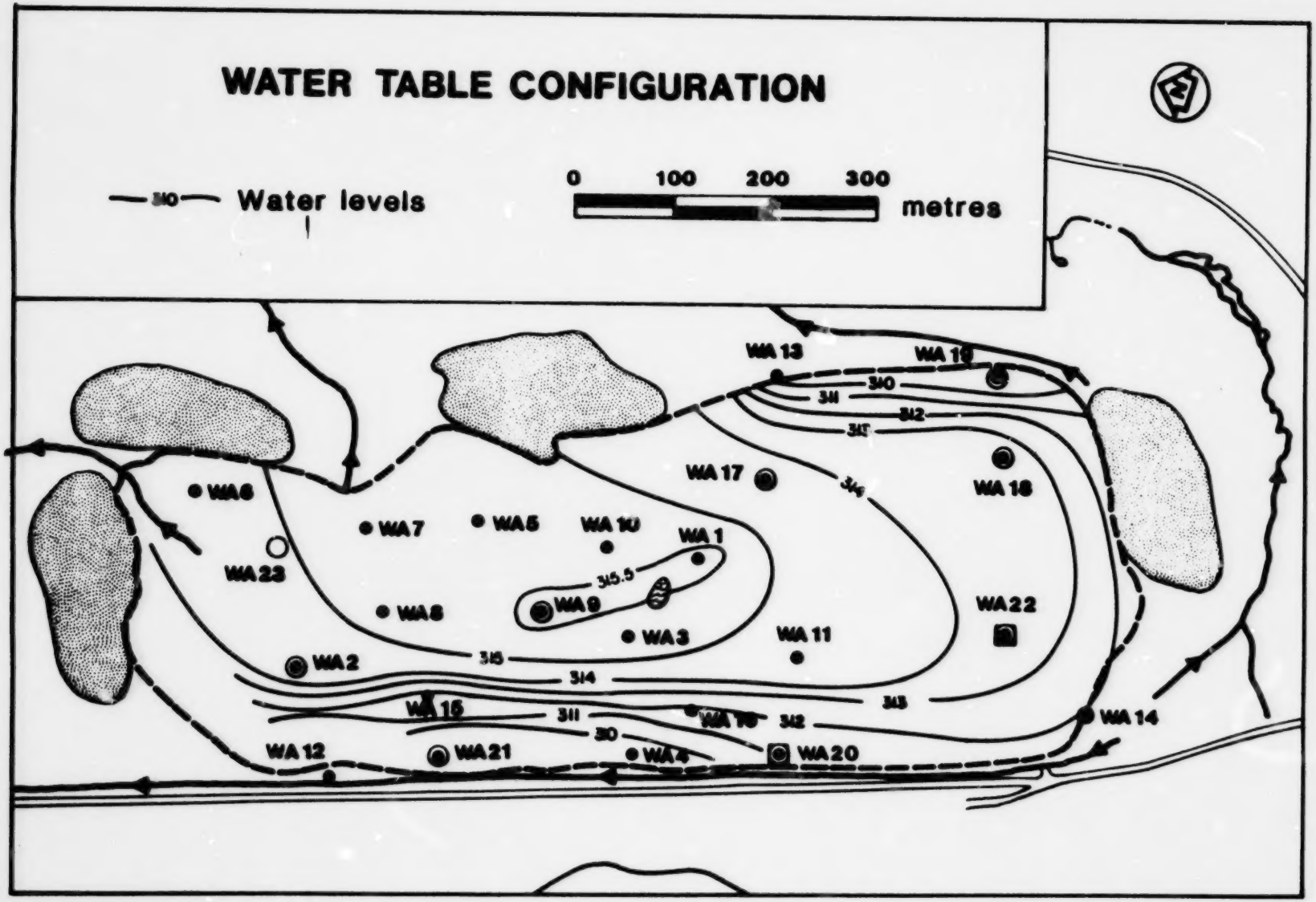

Figure 4 - Piezometer Nest Location and Water Table Configuration

2.3 Tailings Porewater Geochemistry

With the installation of the piezometers, the saturated zone porewater samples could be collected. The wells were evacuated using a peristalic pump, hand-operated vacuum pump or purging them with nitrogen gas, allowed to refill, and then a porewater sample was taken. The first set of piezometer samples was done in December and difficulty arose with freezing of the lines when pumping the wells. Only 10 of the 53 wells were sampled.

2.4 Tailings Mineralogy

Core samples were taken using a hollow stem auger 10.8 cm ID equipped with a 1.5 m split barrel sampler. An 8 cm long sample was cut every 30 cm and stored in a polypropylene sample jar and were shipped to CANMET Elliot Lake Laboratories. The remainder of the 30 cm sample was placed in an air-tight sample bag, the air evacuated and the bag sealed. These samples were shipped to Noranda Research, bagged an additional time, put into 10 L pails and frozen. A scan of only 10 core samples for mineralogical analysis was undertaken by CANMET's Mineral Science Laboratory (MSL) to date.

2.5 Tailings Bacterial Activity

An additional $5,000 was added to the contract for Laurentian University, to undertake the bacterial counts. This provided quantification of only 25 samples for *Thiobacillus ferrooxidans* and sulphate-reducing bacteria. The samples were collected in sterile urine sample bottles using tongue depressers, and packed

tightly to minimize exposure of any sulphate-reducing bacteria to oxygen and cooled. The samples were collected on 20 October 1985, refrigerated and delivered to Laurentian University on 24 October 1985. Methods and materials used to enumerate bacterial colonies are detailed in Appendix B.

2.6 Quality Control Assurance

The seismic survey proved successful and correlated well with the core sample data. Interpretation and application of the other geophysical techniques used cannot be assessed until the mineralogical work is completed.

The site hydrogeology was determined by piezometer installation. Rather than bundled piezometer nests, each piezometer was individually placed with a vertical spacing of at least 1 m, per standard methods([7]).

The saturated tailings porewater was sampled at only 10 piezometers due to winter conditions. Samples were collected per standard practices([7]). Blanks and replicates were not included for these initial samples, but will be for subsequent sampling.

The core samples were collected using a split barrel sampler, identified and stored either in sample jars, or in air tight bags which were then frozen. A methodology to ensure sample integrity during processing for mineralogical analysis is under review by CANMET.

The sampling and analytical techniques for bacterial analysis were discussed with Dr. Ferroni and Dr. N. Davé prior to sample collection to ensure bacterial colony survival. As described in the previous section, the samples were placed promptly into glass jars which were completely filled. The bacterial examination was conducted within about three days.

3. DISCUSSION OF RESULTS OF THE 1985 FIELD PROGRAM

3.1 Geophysical Interpretation

Geophysical methods concurrent with piezometer installations provided a skeletal look at the underlying geologic materials. Seismic results indicate bedrock topography to be extremely variable, expecially in the northern section of the tailings (Figures 5 to 9). The underlying clay is moderately irregular as it gently slopes south and west across the site with thickness varying from 2 m to 20 m. The tailings vary in thickness from 2 m to 15 m from north to south. In the north section (Figure 9), the interface between the clay and bedrock is below the tailings and a downward hydraulic gradient indicates possible tailings porewater movement into the underlying gravelly lense.

The seismic investigation correlated well with the cored boreholes. (Interpretation of the electrical conductance geophysical methods can only be undertaken after the mineralogical analysis has been performed on 9 core samples).

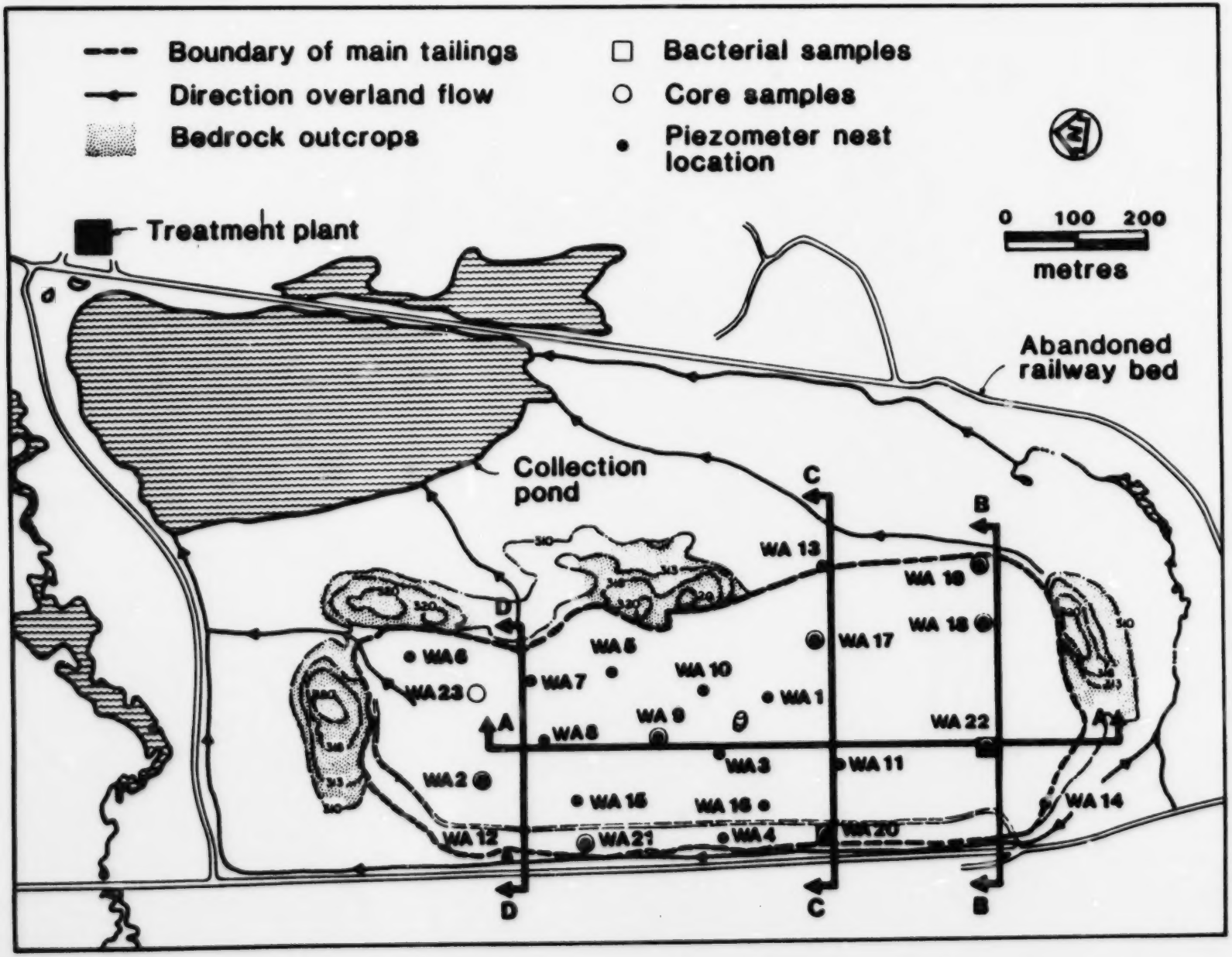

Figure 5 - Location of Waite Amulet Cross Sections

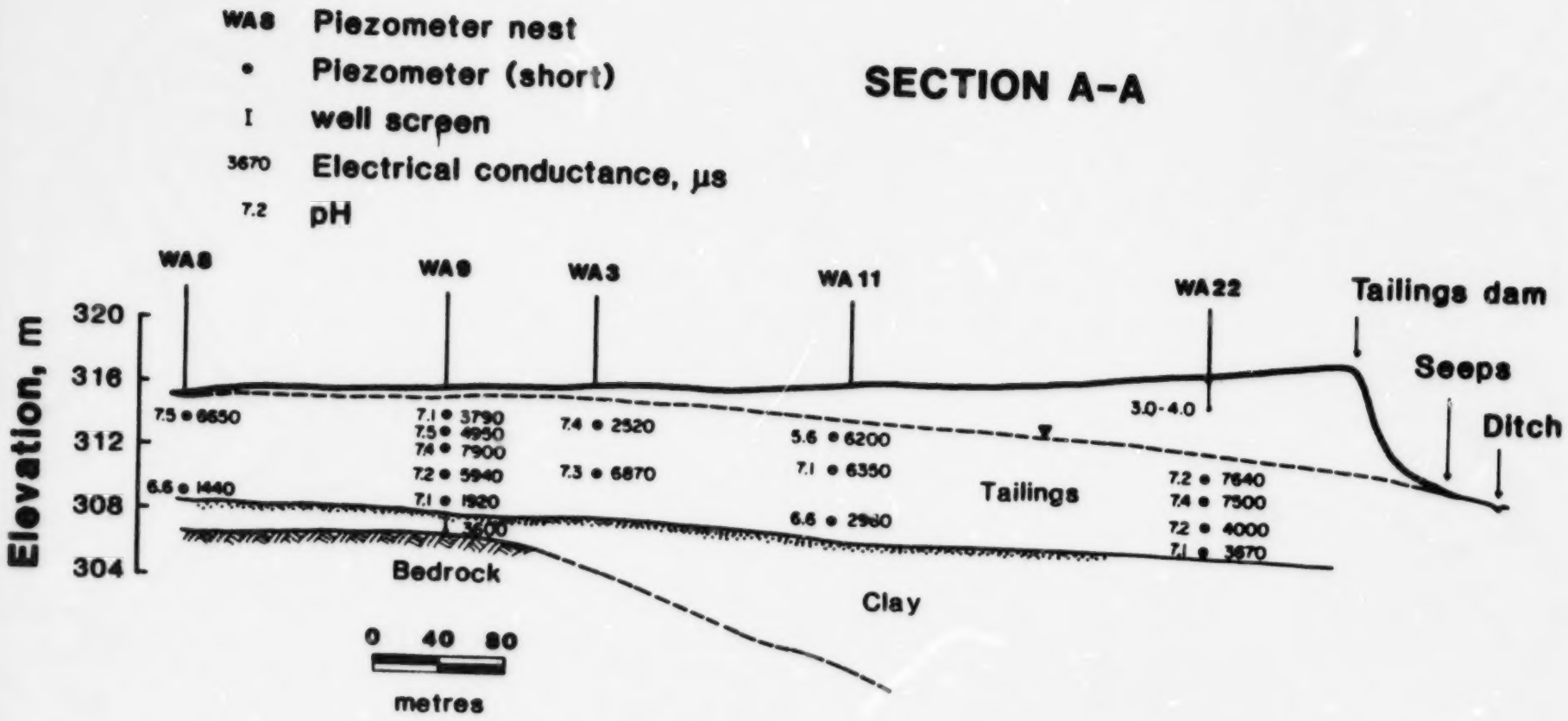

Figure 6 - Section A-A

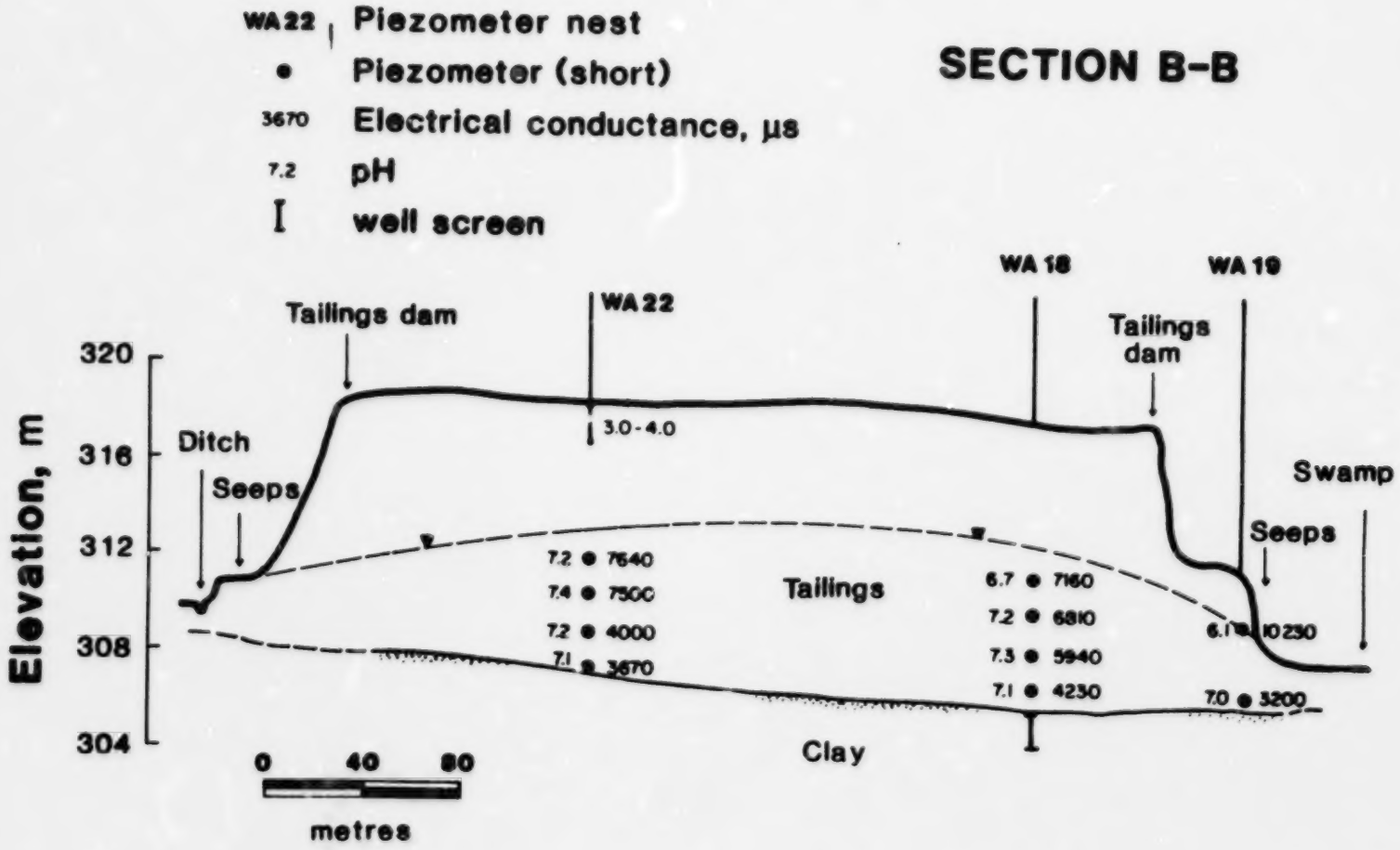

Figure 7 - Section B-3

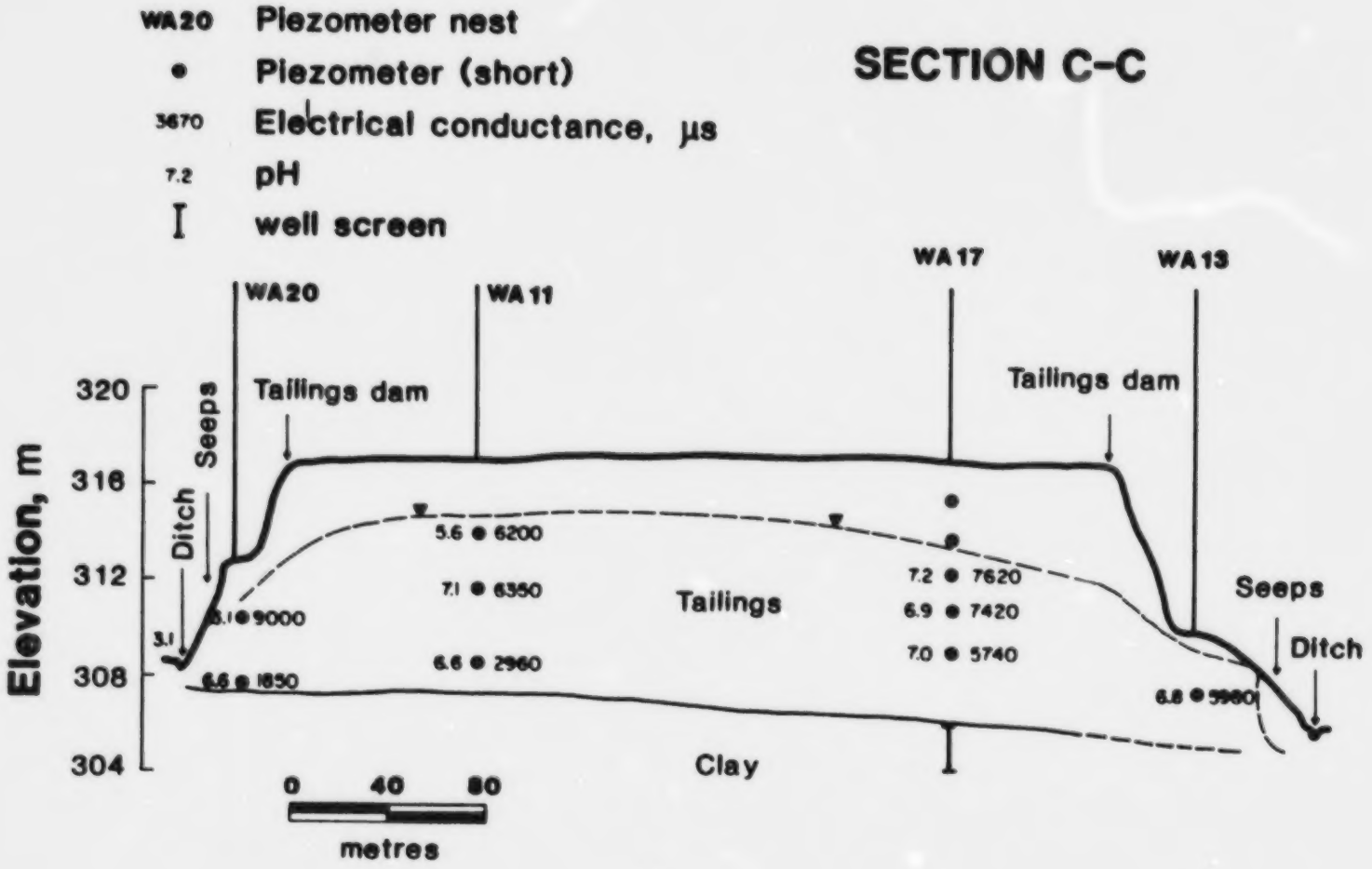

Figure 8 - Section C-C

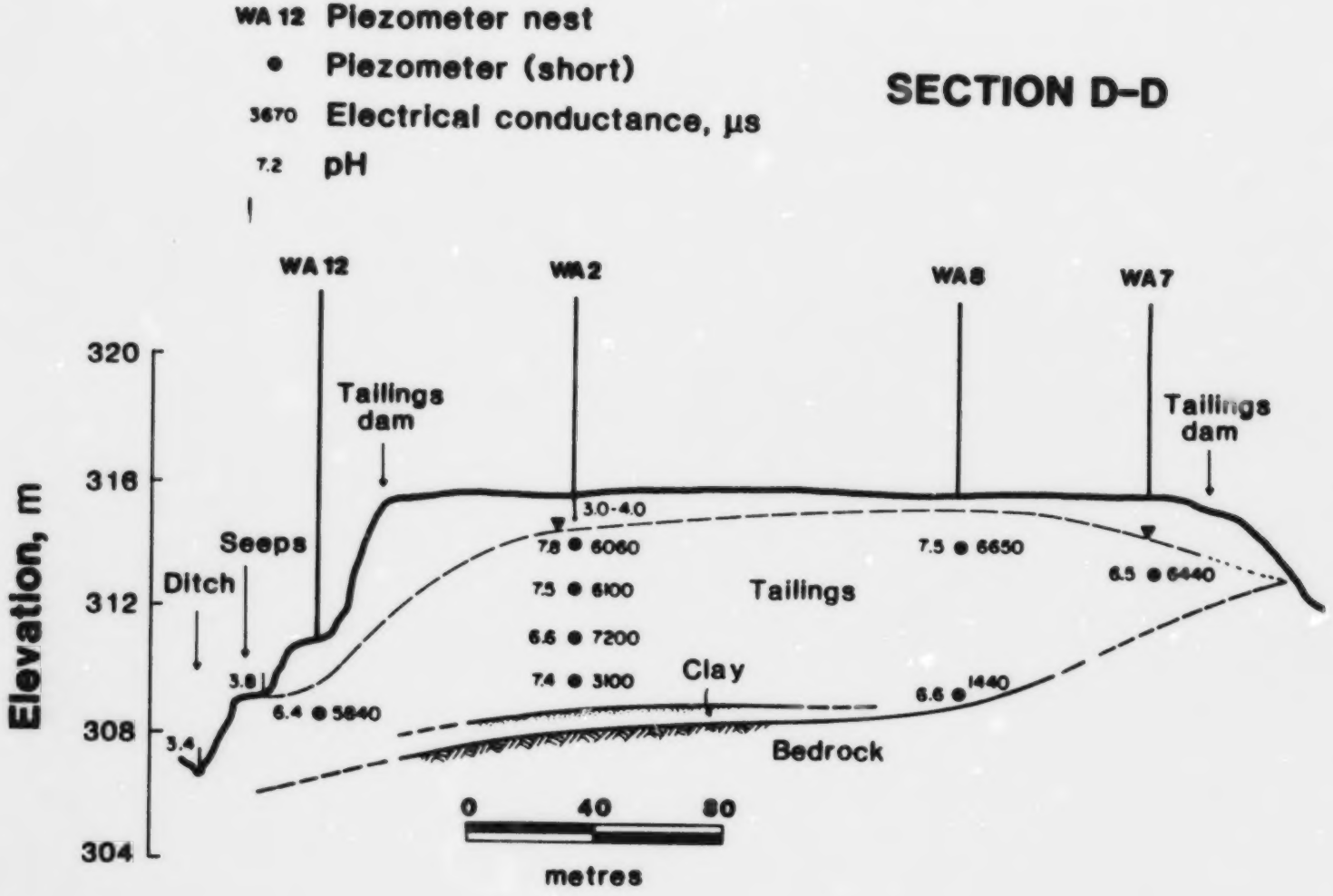

Figure 9 - Section D-D

3.2 Water Table and Hydraulic Conductivity

The water table configuration is illustrated in Figure 4. Only one surface runoff discharge point exists at the north end of the tailings. Otherwise, all precipitation either reports to the tailings as porewater or is evapo-transpirated. The water table conforms to the dam shape prior to discharge; that is, the water table contours are parallel to the seepage face.

The water table is just below the tailings surface in the northern region and up to 5.5 m below the tailings surface in the southern portion. Figure 5 illustrates the locations of the four cross-sections depicted in Figures 6-9. Section A-A, Figure 6, illustrates the near surface water table in the northern region and deep water table in the southern regions. Section B-B, C-C and D-D in Figures 7-9 indicate the increasing water table elevation towards the northern section.

Low hydraulic conductivities were found in the fine-grained northern region and along the central section of the tailings. Higher hydraulic conductivities were observed in the southern section and along the tailings dam perimeter. The results ranged from 9×10^{-7} to 1.4×10^{-3} cm/s, and are detailed in Appendix C, Table I, pages 56-57.

The porewater velocity estimates within the tailings range from 0.4 cm/y to 5 m/y. Tailings porewater velocities across the tailings dam may be up to 35 m/y indicating that the majority of tailings porewater exits via the sides of the dam.

The mineralogy and engineering properties of the samples have not yet been assessed and, therefore, porosity (n) can only be assumed.

3.3 Hydrochemistry of Saturated Zone

Figures 6-9 report the pH and electrical conductance of the porewater in the piezometers. Once the piezometer was installed, it was allowed to fill with porewater. When the water level stabilized, the piezometer was pumped out and allowed to recharge with fresh porewater. pH and electrical conductivity were then taken. The pH was found to be generally above 6 below the water table.

On 5 December 1985, 10 piezometers were evacuated, allowed to recharge and sampled. The analysis of field observations and analytical results are reported in Table III. Piezometer nests 11 and 22 indicate an increase in pH and decrease in porewater metal concentration with depth.

Noranda is currently sponsoring a University of Waterloo PhD candidate, D. Blowes, who is characterizing the geochemistry of three of Noranda's tailings sites. D. Blowes collected two preliminary core samples in the unsaturated zones at PWA-2 and PWA-22. Preliminary indications are that pH increases from 3 to 6 with depth, in the unsaturated zone.

A complete assessment of the hydrochemistry of the saturated zone will be undertaken in the spring of 1986. The unsaturated zone

TABLE III

ANALYTICAL RESULTS OF 10 POREWATER SAMPLES COLLECTED 5 DECEMBER 1985

		PWA Sample Location									
		2-1	11-1	11-2	11-3	20-1	20-2	22-1	22-2	22-3	22-4
Depth	(m)	6.96	8.64	6.17	3.99	6.14	4.06	11.7	9.30	8.08	7.72
pH		6.8	7.0	6.8	5.5	7.5	6.3	7.0	7.0	6.1	5.7
Eh		244	214	242	302	404	294	189	194	224	294
Ec field	(us)	-	2100	4900	-	-	-	-	2200	4500	3600
Ec lab	(us)	3080	2950	5800	8000	1250	6700	2500	3600	6000	6000
Temp field	(^{o}C)	-	4	6	-	-	-	-	5	5	5
Temp lab	(^{o}C)	18	15.5	16.5	18	16	17	25	21	21	21
Acidity	(mg/L)	44	40	336	5400	40	12	139	54	598	1500
Alkalinity	(mg/L)	160	90	90	-	500	44	530	184	40	24
Al	(mg/L)	0.25	0.26	0.31	0.71	0.04	0.38	0.14	0.26	0.30	0.48
Ca	(mg/L)	369	91	498	416	-	453	292	457	531	496
Co	(mg/L)	<0.00	<0.00	0.68	15.6	<0.00	5.30	<0.00	0.00	2.11	4.33
Cu	(mg/L)	<0.00	<0.00	<0.00	<0.03	<0.00	0.02	0.01	<0.00	<0.00	0.01
Fe	(mg/L)	10.0	6.60	198	3940	1.97	1480	23.5	9.32	671	1410
K	(mg/L)	<0.00	61.9	146	67	<0.00	336	-	70.3	73.8	55.6
Mg	(mg/L)	51.7	107	1380	781	20.4	1430	143	371	1290	958
Mn	(mg/L)	1.54	0.61	951	73	0.63	19.4	0.65	0.52	9.7	14.9
Na	(mg/L)	589	1040	61.3	268	422	87.6	-	219	61.4	28.7
Ni	(mg/L)	0.09	0.04	0.18	0.71	<0.00	0.30	0.11	0.11	0.23	0.44
NH_4	(mg/L)	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00
Pb	(mg/L)	0.15	0.06	0.27	1.54	0.04	0.59	0.13	0.18	0.40	0.58
Zn	(mg/L)	0.10	0.02	0.07	1.54	<0.00	0.35	0.06	0.02	0.15	0.36
SO_4	(mg/L)	3060	3120	1020	14700	626	1 2200	2640	4370	9820	9380

testwork will intensify with the 1986 program.

3.4 Bacterial Activity

Analysis of samples for the presence of Thiobacillus ferrooxidans and sulphate-reducing bacteria were conducted by Dr. G. Ferroni, Laurentian University and are reported in detail in Appendix B. The depth reported in Appendix B, Table II are the lengths from which the samples for bacterial analysis were taken. Table II indicates the strong presence of Thiobacillus ferrooxidans above the water table for both boreholes. Sulphate-reducing bacteria were not detected in the majority of the samples below the water table.

4. RECOMMENDED 1986 FIELD PROGRAM

The 1986 program will resolve hydrogeological uncertainties concerning the site, evaluate the geochemistry of the unsaturated zone and dam face, and assess oxidation control options for 1987.

4.1 Finalize Site Hydrogeology

A downward hydraulic gradient in the northern section indicates a possible hydraulic connection between the clay and the underlying rock. The flow direction of the saturated zone and seepage face will be firmed up.

4.2 Evaluate Geochemistry of Unsaturated Zone and Dam Face

An investigation of the biohydrogeochemical processes and controlling mechanisms of the unsaturated zone and dam face will be undertaken via:

- analysis of core samples and porewater samples in the unsaturated zone;
- monitoring of the oxygen profile;
- monitoring of metal loadings and flow through and out of tailings;
- monitoring of rainfall and evaporation.

4.3 Assess Oxidation Control Options for 1987

The Waite Amulet tailings has been revegetated both by directly seeding into the tailings and vegetating a clay cover. Sampling under these areas will in part provide information on their effectiveness as oxygen barriers. The use of wetlands along the northeastern edge will be considered as a control technique.

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APPENDIX A

PROPOSAL FOR HYDROGEOCHEMICAL INVESTIGATION OF REACTIVE TAILINGS AT THE WAITE AMULET TAILINGS SITE

CENTRE DE RECHERCHE NORANDA

DRAFT COPY
18/4/85
Subject to Revision

A PROPOSAL TO: DEPARTMENT OF ENERGY, MINES AND RESOURCES, CANMET

HYDROGEOCHEMICAL INVESTIGATION OF REACTIVE SULPHIDE TAILINGS AT THE WAITE AMULET TAILINGS SITE, NORANDA, P.Q.

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1. SUMMARY

Specific research priorities for reactive tailings management have been delineated in a report to CANMET([1]) by various mining companies. It was recommended that a detailed hydrogeochemical investigation be completed on a revegetated reactive tailings which this proposal encompasses.

A field study of the abandoned reactive Waite Amulet tailings disposal area will provide:

- An understanding of hydrogeochemical processes and charges in a reactive tailings area.
- Improved long-term reactive tailings management.

The reactive Waite Amulet tailings area study will concentrate on measuring the hydrogeochemistry of the tailings and surrounding strata. This will be accomplished by a two-phase drilling program and monitoring quality and quantity of surface runoff, flow through the tailings mass and groundwater regime. Data acquisition will be temporally varied to evaluate seasonal effects.

The proposed project is estimated to cost $550,000 with a project duration of 5 years.

2. INTRODUCTION

A specific program was recommended to conduct a detailed hydrogeochemical investigations of several sulphide tailings areas based on research priorities indicated to CANMET by various mining companies([1]). The proposed study intends to evaluate a partially revegetated reactive tailings area in general in accordance with program priorities.

3. TECHNICAL PROPOSAL

3.1 Objectives

The field investigation of the abandoned reactive Waite Amulet tailings disposal area near Noranda, Québec will develop a better understanding of the hydrogeochemical processes and charges which occur in an acid-generating tailings area. Understanding these processes will lead to the development of improved long-term tailings management practices. Specifically, the objectives of the detailed hydrogeochemical investigations of the Waite Amulet tailings are:

3.1.1 Measure the hydrogeology of the tailings area and establish local geology, hydrology and surface and ground water regimes.

3.1.2 Measure geochemistry of the tailings area with piezometer nests along the major groundwater flow paths within the tailings and surrounding aquifer for establishing possible contaminant plumes.

3.1.3 Measure quality and quantity of surface water entering and leaving the tailings area.

3.1.4 Obtain core samples from the tailings area and analyze for physical and chemical properties (moisture content, grain size, minerology, etc.) at different depths.

3.1.5 Collect meteorological data and obtain an area water balance.

3.1.6 Assess the effect of vegetation on water quality and quantity and evaluate long-term vegetation viability.

3.1.7 Monitor aerobic and anaerobic bacterial communities to assess zones of oxidization.

3.2 **Justification**

Assessment of closure strategies for long-term tailings management are required to minimize costs and associated problems.

A joint program to study the hydrogeochemical processes at the partially revegetated Waite Amulet tailings will quantify the benefits of a vegetative cover and its viability. Joint programs are likely to be most cost effective.

3.3 **Scope**

3.3.1 1985 Program

Preliminary reconnaissance will evaluate surface water levels and collection of near surface water and soil samples to provide a hydrogeologic setting and extent of tailings deposition. Location of surface runoff monitors and preliminary boreholes will be established during this phase.

Preliminary drilling program will commence with on-tailings and off-tailings boreholes for core sampling and

piezometer installations. Analysis of core samples will provide hydraulic conductivity, porosity grain size, oxidized-unoxidized zones and bacterial counts.

3.3.2 1986 Program

Flow recorders and meteorological equipment will be installed to provide surface hydrology and information on precipitation, evaporation wind direction and wind speed information.

Complete drilling program based on findings of the 1985 drilling program. More boreholes will be required to properly delineate interstitial tailings water and ground water.

Data acquisition program will commence with collection of water samples from surface runoff stations, boreholes and stand pipes. Surface runoff flow rates water table elevations and pore water pressures will be recorded along with climatological data.

3.3.3 1987-1989 Program

Data acquisition program will continue for the 3 years to assess water quality and quantity of surface and groundwater flows in an attempt to provide a water and metal balance for the tailings area. The benefits of a vegetative cover and its viability will be clarified. An understanding of the factors affecting water quality and flow in on and around the tailings dam will be elucidated.

4. **PRICE PROPOSAL**

The total cost of the proposed project will be $550,000

as detailed in Table I. The project schedule and anticipated cash flow will be as per Figure 1.

It is assumed that CANMET will provide at no charge to this project the following services:

- determination of physical/chemical properties of soils
- bacterial counts
- computer and modelling services
- 1-1.5 person years per year for field assistance, data analysis and report preparation.

4.1 Labour

Billing rates for Noranda Research Centre personnel will be in accordance with the following negotiated rate (not to exceed $500/day or $68.97/h for 7.25 h/day).

$$\text{Hourly rate} = \frac{\$\text{annual} + 159\% \text{ overhead}}{1885 \text{ hours}}$$

4.2 Equipment, Materials, Shipping

All items will be billed at cost with no mark-up.

4.3 Travel and Living

Cost will be in accordance with Noranda Research and DSS guidelines and will be billed at cost with no mark-up.

4.4 Disbursements

Cost re telephone, telex, printing, etc. will be billed at cost with no mark-up.

4.5 Price Certification

We hereby certify that the price quoted is based on costs computed in accordance with Costing Memorandum DSS 1031, a copy of which we acknowledge to have received, and that the price

does not contain an element of profit in excess of 0%.

4.6 Joint Costing Approach

It is suggested that the following cost sharing program be adopted.

	1985	1986	1987	1988	1989	Total
CANMET	75,000	125,000	45,000	15,000	15,000	275,000
Noranda	25,000	100,000	30,000	60,000	60,000	275,000
	$100,000	$225,000	$ 75,000	$ 75,000	$ 75,000	$550,000

REFERENCE

1. Monenco Limited, Sulphide Tailings Management Study, report to CANMET, 25 June 1984.

TABLE I

DETAILED COST ESTIMATES

	Labour	Material	Contract	Total
1985 Program				
Preliminary Reconnaissance				
- water table evaluation	15,000	5,000		20,000
- surveying			5,000	5,000
- water analysis			5,000	5,000
				$ 30,000
Preliminary Drilling Program				
- site supervision	15,000			15,000
- drilling, core sampling	5,000		46,000	51,000
- surveying	-	4,000		4,000
				$ 70,000
			1985 Total:	$100,000
1986 Program				
Flow recorder-meterological equipment				
- site supervision	10,000			10,000
- climateological station		15,000	5,000	20,000
- flow recorders/samplers		40,000	5,000	45,000
				$ 75,000

Note: Labour includes lodgings and transportation for Noranda Research and site supervision by Noranda Inc., Horne Division, Noranda, P.Q

TABLE I (Cont'd)

DETAILED COST ESTIMATES

	Labour	Material	Contract	Total
Complete drilling program				
- site supervision	10,000			10,000
- drilling core sampling			30,000	30,000
- surveying			5,000	5,000
- additional flow recorders	5,000	20,000	5,000	30,000
				$ 75,000
Data Acquisition				
- data collection	10,000		25,000	35,000
- water analysis			25,000	25,000
- analysis and reporting	15,000			15,000
				$ 75,000
			1986 Total:	$225,000
1987 Program				
- analysis and reporting	30,000			30,000
- data collection			25,000	25,000
- water analysis			20,000	20,000
			1987 Total:	$ 75,000
1988 Program				
- analysis and reporting	30,000			30,000
- data collection			25,000	25,000
- water analysis			20,000	20,000
			1988 Total:	$ 75,000
1989 Program				
- analysis and reporting	50,000			50,000
- data collection			15,000	15,000
- water analysis			10,000	10,000
			1989 Total:	$ 75,000

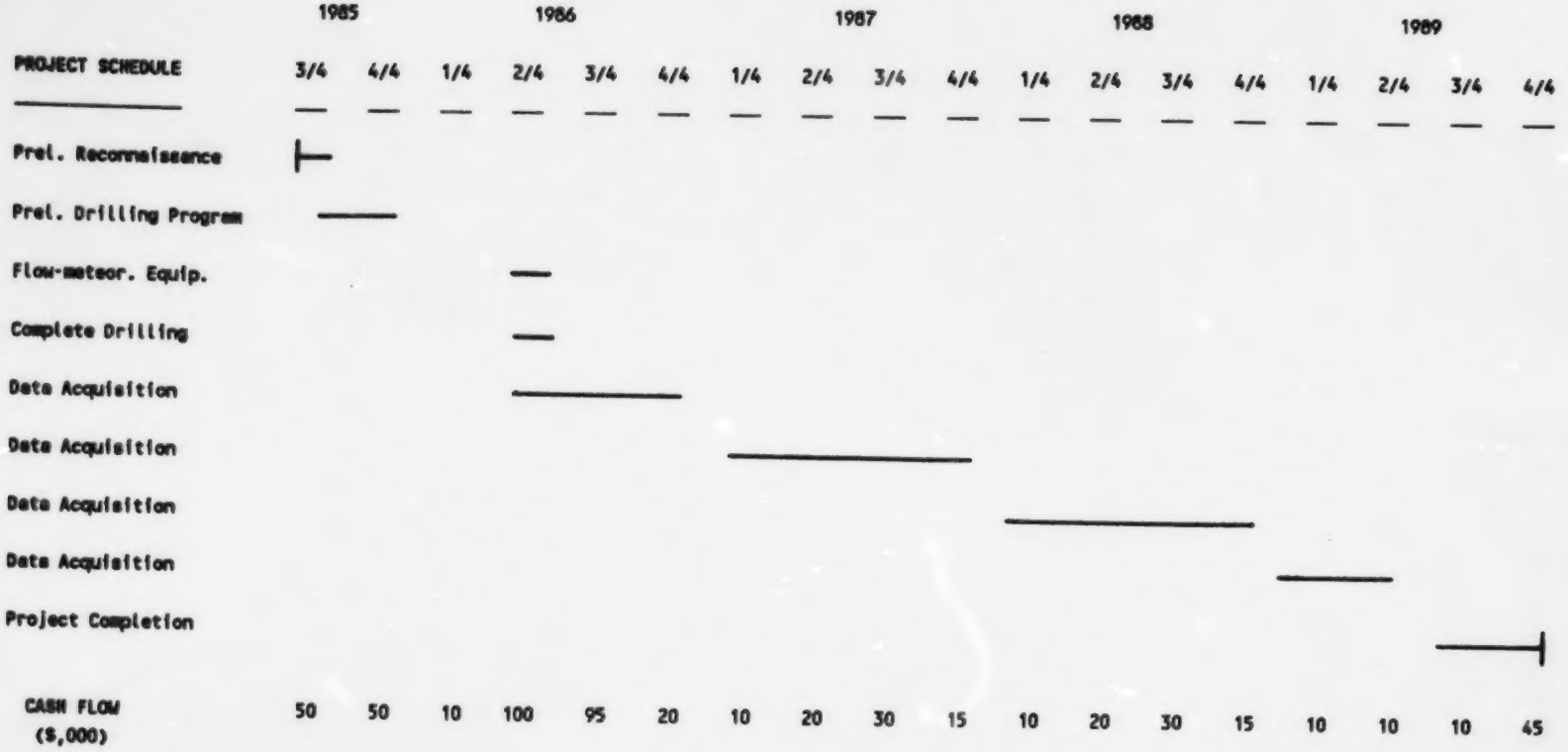

Figure 1 - Project Schedule and Cash Flow

APPENDIX B

QUANTIFICATION OF THIOBACILLUS FERROXIDANS AND SULPHATE-REDUCING BACTERIA IN CORE SAMPLES FROM THE WAITE AMULET TAILINGS

QUANTIFICATION OF *THIOBACILLUS FERROOXIDANS* AND SULFATE-REDUCING BACTERIA IN CORE SAMPLES FROM THE WAITE AMULET TAILINGS

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December 9, 1985

OBJECTIVES

1. To determine the most probable numbers of Thiobacillus ferrooxidans and sulfate-reducing bacteria in 25 core samples collected from the Waite Amulet tailings.

2. To measure the pH and water content of the samples.

MATERIALS AND METHODS

Sampling

Twenty-five tailings samples were delivered to Laurentian University on October 24, 1985. These samples had been collected on October 20, 1985, by coring, at the Waite Amulet tailings. The samples were refrigerated prior to delivery to Laurentian University.

Upon receipt of the samples, they were checked for leakage, labelled according to the protocol in Table 1, and refrigerated at 2°C.

Culture media

The medium used to enumerate Thiobacillus ferrooxidans was the modified 9K medium of Silverman and Lundgren (1959), referred to as medium 9K (see Appendix, Table 1 for composition). This medium had a final pH of 2.5. The basal salts and energy source were autoclaved separately to prevent excess precipitate formation.

The medium used to enumerate sulfate reducers was Medium B of Postgate (1966; see Appendix Table 2 for composition). This medium had a final pH of 7.0.

Most Probable Number Method

The method of enumeration for Thiobacillus ferrooxidans

and sulfate reducers was a 5 x 5 most probable number (MPN) one; that is, 5 replicates of 5 dilutions of each sample were employed. The MPN method, in each case, provided an estimate of the number of bacteria per gram dry weight of tailings sample.

Enumeration of sulfate reducers

Cores of the samples in their containers were collected using the barrel, with its closed end cut off, of a sterile 30-ml syringe. This procedure was adopted in order to yield a representative sample. Ten grams (wet weight) were added to a 250-ml Erlenmeyer flask containing 100 ml of Medium B. The flasks were flushed with liquid nitrogen for 2 min. to remove oxygen which might kill any oxygen-sensitive cells during the subsequent mixing period. The flask contents were mixed for 2 min. by gyrotation to provide a sample homogeneous with respect to bacterial cells. From this sample (considered to represent a 10^{-1} dilution), ten-fold dilutions up to 10^{-5} were made. One ml of each dilution was added, in quintuplicate, to 10 ml of Medium B contained in culture tubes. Incubation was carried out for 28 days at 25°C-27°C in anaerobic jars. Tubes were scored positive for sulfate reducers if a blackening of the medium had occurred.

Enumeration of Thiobacillus ferrooxidans

Cores of the samples were taken and initial dilutions were made as described for sulfate reducers. Similarly, one ml of each of the 5 dilutions (10^{-1}-10^{-5}) was added, in quintuplicate, to 10 ml of 9K medium contained in culture

tubes. Incubation was carried out at 26°C and the tubes were mixed every 7 days of the incubation period. A reddening of the medium was indicative of the growth of Thiobacillus ferrooxidans . Observations were made at 21 days and again at 28 days.

Measurement of sample pH

Five-gram amounts of each sample were added to 10 ml of distilled water. The suspensions were immediately mixed, using a vortex mixture, for 15 seconds, and allowed to stand for 30 minutes. pH measurements were made with a Fisher Accumet pH meter.

Dry weight determinations

Approximately 10-gram samples were added to aluminum weighing trays and exact wet weights were determined before the samples were dried for 48 h at 85°C. After dessication, the dried samples were weighed to a constant weight (to 3 decimal places).

Table 1. Sample codes and depths

LAURENTIAN CODE	NORANDA CODE	SAMPLE DEPTH (FT)
N-1	WA-20	1-2
N-2	WA-20	2-4
N-3	WA-20	4-6
N-4	WA-20	6-8
N-5	WA-20	8-10
N-6	WA-20	10-12
N-7	WA-20	12-14
N-8	WA-20	14-16
N-9	WA-22	1-1.4
N-10	WA-22	1.4-2
N-11	WA-22	2-5
N-12	WA-22	5-8
N-13	WA-22	8-11
N-14	WA-22	11-14
N-15	WA-22	14-17
N-16	WA-22	17-18.5
N-17	WA-22	18.5-19
N-18	WA-22	19-22
N-19	WA-22	22-25
N-20	WA-22	25-28
N-21	WA-22	28-31
N-22	WA-22	31-34
N-23	WA-22	34-36.5
N-24	WA-22	36.5-38.7
N-25	WA-22	38.7-39

RESULTS

The results for the most probable number of Thiobacillus ferrooxidans , the most probable number of sulfate reducers, and pH, for the 25 tailings samples, are presented in Table 2.

For core WA-20 and core WA-22, pH increased with increasing depth, the extremes for the former being 3.39 (2 ft) and 7.00 (16 ft) and for the latter 3.40 (1.4 ft) and 8.09 (39 ft).

For core WA-20, Thiobacillus ferrooxidans was detected in 6 of 8 samples and sulfate reducers were detected in 2 of 8 samples. For core WA-22, Thiobacillus ferrooxidans was detected in 3 of 17 samples and sulfate reducers were detected in 5 of 17 samples. The highest estimates for Thiobacillus ferrooxidans were more than two orders of magnitude greater than the highest estimate for sulfate reducers.

Table 2. Most probable number estimates of Thiobacillus ferrooxidans and sulfate reducers, pH, and water content, for 25 tailings samples.

Sample	Depth (ft)	%H_2O	pH	Dry Wt (g)	T.ferro oxidans MPN/g	Sulfate reducers MPN/g
Core WA-20						
N-1	1-2	18.9	3.39	8.12	4052	0
N-2	2-4	10.9	4.09	8.91	60859	0
N-3	4-6	9.9	4.00	9.01	8795	0
N-4	6-8	14.1	4.23	8.59	91	2
N-5	8-10	11.8	5.06	8.82	1214	0
N-6	10-12	11.4	5.26	8.86	0	0
N-7	12-14	11.2	5.48	8.88	2	0
N-8	14-16	11.7	7.00	8.83	0	554
Core WA-22						
N-9	1-1.4	19.8	3.40	8.02	>100,000	16
N-10	1.4-2	18.3	3.96	8.17	>100,000	0
N-11	2-5	4.0	4.18	9.60	95609	0
N-12	5-8	11.4	4.07	8.86	0	2
N-13	8-11	4.1	5.59	9.59	0	0
N-14	11-14	5.6	5.85	9.44	0	0
N-15	14-17	11.8	5.85	8.82	0	0
N-16	17-18.5	16.3	6.68	8.37	0	0
N-17	18.5-19	17.8	6.78	8.22	0	0
N-18	19-22	15.7	6.34	8.43	0	9
N-19	22-25	14.8	6.70	8.52	0	270
N-20	25-28	14.1	6.98	8.59	0	0
N-21	28-31	13.4	7.46	8.66	0	0
N-22	31-34	13.9	7.45	8.61	0	2
N-23	34-36.5	15.8	7.57	8.42	0	0
N-24	36.5-38.7	22.1	6.87	7.79	0	0
N-25	38.7-39	20.4	8.09	7.97	0	0

INTERPRETATIONS

1. The upper depths of Core WA-22 are more abundant with regard to Thiobacillus ferrooxidans than the upper depths of Core WA-20.

2. The presence of Thiobacillus ferrooxidans is related to pH and depth, reflecting its preference for an aerobic, acidic environment.

3. The maximum estimates for Thiobacillus ferrooxidans were in excess of 100,000 cells per gram dry weight of sample.

4. Both Core WA-20 and Core WA-22 have low numbers of sulfate reducers. And, we feel that such low numbers are not due entirely to the possible oxygen sensitivity of the indigenous bacteria. The sulfate reducers are anaerobes which, besides being unable to grow in the presence of molecular oxygen, require organic compounds as a carbon/energy source and sulfate ion (or sulfite or thiosulfate or other oxidized sulfur compounds) as a terminal electron acceptor. Many of the sulfate reducing bacteria are not extremely oxygen sensitive. NOTE: Exposure to molecular oxygen would have occurred during sampling and during the laboratory processing of the samples.

ACKNOWLEDGEMENTS

We are indebted to Mr. Marty Todd for his skillful technical assistance and diligence.

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APPENDIX

Table 1. Medium B of Postgate (1966)

Compound	Amount per L
KH_2PO_4	0.5 g
NH_4Cl	1.0 g
$CaSO_4.2H_2O$	1.23 g
$MgSO_4.7H_2O$	2.0 g
lactic acid	2.32 ml
yeast extract	1.0 g
ascorbic acid	1.0 g
thioglycollic acid	0.75 ml
$FeSO_4.7H_2O$	0.5 g
adjust pH to between 7.0 - 7.5	

APPENDIX

TABLE 2. Medium 9K of Silverman and Lundgren (1959).

Component	Amount
Basal Salts:	
$(NH_4)_2SO_4$	3.0 g
KCl	0.10 g
K_2HPO_4	0.50 g
$MgSO_4.7H_2O$	0.50 g
$Ca(NO_3)_2$	0.01 g
Distilled Water	700 ml
pH to 3.0 with 1.0 N H_2SO_4	
Energy Source:	
$FeSO_4.7H_2O$	44.22 g (4.4%)
Distilled Water	300 ml

APPENDIX C

A PRELIMINARY HYDROGEOLOGICAL INVESTIGATION OF THE WAITE AMULET TAILINGS

TERRAQUA INVESTIGATIONS LTD.

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A PRELIMINARY HYDROGEOLOGICAL INVESTIGATION OF THE WAITE AMULET TAILINGS

January 1986

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1. INTRODUCTION

1.1 Objectives of the Study

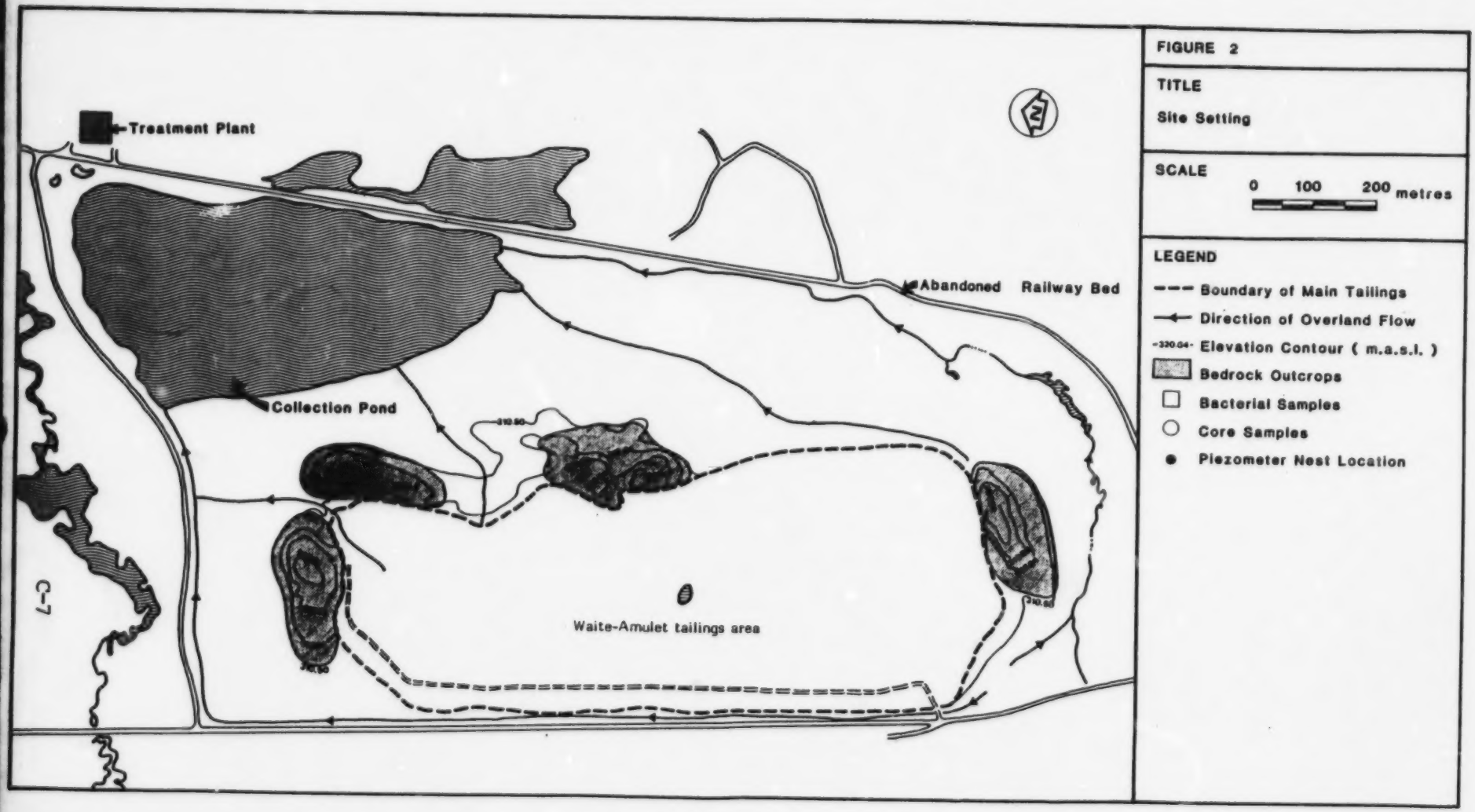
The study described in this report was carried out in response to a request for proposals by the Noranda Research Centre. The major objective of the overall study by the Noranda Research Centre is to undertake a five year hydrogeochemical investigation of the Waite Amulet tailings area near Noranda, Quebec. The study is part of a joint industry/CANMET Reactive Tailings Program to examine the hydrogeochemical evolution and processes occurring in reactive tailings.

The objectives of the present study were twofold. The first objective was to better define the extent and variation of tailings deposition and type of geologic material underlying the tailings by use of various geophysical and drilling methods. Samples of tailings solids and underlying geologic materials were collected during drilling, for detailed physical and chemical analysis. The second objective was to install a piezometer network to allow a preliminary assessment of the hydrogeological and geochemical conditions within and below the tailings.

1.2 Site Setting and History

The Waite Amulet tailings area is located approximately 25 km north of Noranda, Quebec (Figure 1). The main tailings area is

FIGURE 1 SITE LOCATION


Treatment Plant
Abandoned Railway Bed
Collection Pond
Waite-Amulet tailings area
C-7
FIGURE 2
TITLE
Site Setting
SCALE
0 100 200 metres
LEGEND
Boundary of Main Tailings
Direction of Overland Flow
Elevation Contour (m.a.s.l.)
Bedrock Outcrops
Bacterial Samples
Core Samples
Piezometer Nest Location

approximately 40 hectares in size (Figure 2). The Waite Amulet Mine ceased production

in October 1962 leaving on the order of six million tons of high sulphide tailings at the site during the 40+ years of operation. Tailings from several other mine sites were also deposited at the Waite-Amulet tailings area.

Dam construction was done by spigotting in the summer and end spilling during the winter. The tailings dam is two benched and is approximately 12 m above the surrounding area. A portion of the area is bounded by bedrock outcrops, primarily in the northeast portion of the site. Prior to the commencement of this study it was assumed that the tailings were deposited on a varved clay which was on the order of 6m in thickness. This clay overlies the bedrock.

Oxidation of sulphide minerals in the tailings resulted in generation of acidic seepage water along the perimeter of the tailings dam. At the interface of the oxidized and unoxidized tailings a thin layer of "hardpan" was found.

In 1969, Noranda initiated a revegetation program in an effort to reduce acidic seepage and air-borne particulate matter from the tailings. This was unsuccessful and Noranda undertook extensive research into tailings reclamation. Large scale reclamation

recommenced in 1978. By 1982, most of the tailings area had been revegetated.

The quality of seepage water from the tailings did not appear to change, as the pH was still low (2-3) and resulted in mobilization of numerous heavy metals (Fe, Zn Cu). As part of the reclamation program, uncontaminated streams within the watershed in which the Waite-Amulet tailings are located were diverted around the tailings area. The acid seepage from the tailings dam is presently being collected in five main streams and diverted to a pond northeast of the tailings (Figure 2) where the water is treated and discharged via Duprat Creek to Lake Dufault east of the tailings area.

Study Team

The main study team comprised of Mr. R. Blackport from Terraqua Investigations Ltd. and Mr. P. Pehme on contract from Waterloo Geophysics Ltd.

Mr. Blackport was responsible for the overall project management and the hydrogeological aspects of the investigation including field work, data analysis and report preparation. Mr. Pehme was responsible for the geophysical component of the investigation including all field work, data interpretation and report preparation.

2. METHODS OF INVESTIGATION

2.1 Geophysical Methods

As part of the preliminary hydrogeologic survey of the Waite-Amulet tailings impoundment a geophysical survey was undertaken to determine the thickness of the tailings and underlying clay, topographic variations in the underlying bedrock and conductivity variations across the tailings. The geophysical investigation consisted of seismic refraction, electromagnetic surveys and resistivity surveys. The majority of the work was done on the main tailings area (Figure 2). The area around the site was investigated locally to determine the applicability of geophysical methods for detecting groundwater contaminant migration in this type of site setting.

A combination of geophysical techniques and equipment was used to give flexibility to the coverage required and be cost effective. This approach appears to be the most suitable when investigating a site with limited data available prior to the investigation. Two different parameters were measured, seismic velocity and electrical conductivity, to decrease the probability of an unsuccessful survey due to unknown site conditions.

Seismic refraction data give detailed vertical information along traverses. Electromagnetic surveys give broad lateral information across the site. Resistivity soundings are used to give site specific

variations in vertical electrical conductivity. The penetration depth of these methods are variable and are used to examine vertical variations in electrical conductivity across the site. A large number of measurements are taken in a detailed grid pattern across the site to establish lateral variations across the site.

A brief description of the techniques utilized are discussed below. For a more detailed description of Electromagnetic Conductivity, see McNeill (1980). For a more detailed description of both Seismics and Resistivity methods, see Telford (1976).

Resistivity

Direct current resistivity soundings measure the apparent resistivity of the ground through which an induced electrical current passes. The resistivity of the ground varies according to the grain size and water content of the material through which the electrical current passes. A current flow is induced through the ground between two electrodes. Two other electrodes are used to measure the potential voltage drop in the ground between the two electrodes. The depth of penetration of the electrical current is directly proportional to the distance between the current electrodes. By systematically increasing the distance between current electrodes vertical variations in electrical conductivity, and hence variations in stratigraphy, can be measured.

Seismic Refraction

The seismic refraction technique measures variations in the velocity that a shock wave or pulse propagates along boundaries of geologic units. It is assumed that seismic velocities of units increase with depth as is generally the case.

A vibration is created by either a sledge hammer blow or a small explosion. To detect the vibration, a series of geophones are used. Typically, 12 geophones are placed at regular intervals from the source of vibrations. Close to the source the first vibration reaching the geophone has travelled in a straight line along the surface. A plot of travel time versus distance from the source produces a straight line with a slope that is the inverse of the material velocity. As the distance between the source and geophone is increased, a critical distance is reached where the first vibration to arrive at the geiphone is no longer the one travelling along the surface. This vibration has travelled down to a deeper, higher velocity layer, moved along it and has come back to surface. At distances greater than the critical distance, the difference in first arrival travel path for subsequent geophones is an increase in distance along the lower layer. The slope of the time-distance plot becomes the inverse of the higher velocity, in this layer.

Using the source at either end of the geophone spacings, the interface of the high velocity layer, can be calculated using the delay time method presented by Redpath (1976).

Electromagnetic Terrain Conductivity Measurement

The Electromagnetic (EM) system used in this study was designed by Geonics. It is a two coil system. A current moving through the transmitting coil creates a primary electromagnetic field. This field penetrates the ground and induces a small current flow within the earth. The small current creates another (the secondary) EM field. The properties of the secondary field are a function of the electrical conductivity of the ground. Therefore, by detecting the combined primary/secondary field with another coil (the receiver) and removing the effects of the primary field, the ground electrical conductivity is determined.

The instrument yields a bulk conductivity for the earth, down to a penetration depth controlled by the inter coil spacing and orientation.

2.2 Solid Sampling

Tailings solids and underlying geologic materials were sampled to characterize the physical and chemical properties of these materials across the site. It was important to obtain samples which were relatively undisturbed and uncontaminated by addition of material or water from other zones.

Many sampling techniques have been utilized at other tailings sites, with varying degrees of success, depending upon the variation in grain-size and water content (and thus cohesiveness) of the tailings over

large and small vertical intervals. This study utilized the hollow stem auger method of drilling and a specially designed continuous soil sampler. This method worked very well at the Waite Amulet tailings and as a result was the only method utilized during this study. Results of the sampling are discussed in Section 3.2.

A track-mounted CME 75 drill was used for hollow stem augering and sample collection. Hollow-stem augers with 10.8 cm (4.25 in.) ID were used. The continuous sampler system used inside the augers obtained cores 8.25 cm (3.25 in) in diameter and up to 1.5 m in length.

The sampler barrel is a split barrel which is advanced with auger advancement during drilling. The position of the sampler barrel can be adjusted to have a portion of it ahead of the augers or just up inside the lead auger. The adjustment depends on the hardness and cohesiveness of the material being sampled. The continuous sampler system does not turn with the augers as it advances and is in effect pushed ahead similar to obtaining a Shelby tube sample. The sampler barrel is 1.5 m in length and the length of samples collected (i.e. length of auger advancement) varied from 0.75 m to 1.5 m depending on the material being sampled (see Section 3.2).

After a sample run was collected the sampler barrel was removed and split open to examine the sample. The sample was described in field geologic logs and photographed. Because of the large volume of

sample collected, sub-samples of approximately 8 cm were collected for every 30 cm length , and packed in polypropalene sample jars to be shipped to CANMET. Closely spaced samples were collected in zones of interest such as the upper oxidized/unoxidized zone contact in the tailings and the tailings/native geologic material interface. Sample jars were labelled with the borehole number, sample number, depth of sample and date. The remainder of the sample was retained in airtight plastic bags and these samples are being stored by the Noranda Research Centre. A continuous set of samples was collected at the nine sites drilled. Results are discussed in Section 3.2.

2.3 Piezometer Installation

Piezometers were installed utilizing both hand operated and drilling methods. Piezometer installations were done in two phases. Firstly, during a preliminary site visit, to determine the applicability of hand operated methods spatially across the tailings, and secondly, during the solid sampling phase when a drill rig was present to install piezometers where the hand-operated methods were impractical.

Piezometers installed in the tailings were a modified Casagrande drive-point piezometer developed at the University of Waterloo (Blair et al, 1980). It is constructed entirely of plastic material to avoid corrosion in acidic water. A porous polyethylene cartridge with a 50 micron pore size was used for the piezometer screen. The porous cartridge forms a sleeve over a 15 cm by 3 cm Schedule 80 PVC

perforated barrel (Figure 3). The porous cartridge is placed between the drive-point tip and female coupling and sealed with a silicone compound. The porous cartridge was necessary to prevent silt size particles from entering the piezometer. Due to the fine-grained nature of some tailing fractions some "silting" of some piezometers still occurred but did not pose a problem.

Piezometers installed by hand were generally located in fine-grained tailings with a relatively shallow water table (i.e. less than 2 m). Each piezometer was advanced by driving a 1.5 m coupled section of 3 cm ID Schedule 40 PVC pipe attached to the piezometer tip. The pipe was driven either by pounding a steel mandrel and weight on the pipe or by using a percussion drill which fit on an adapted driving head on the steel mandrel. The steel mandrel was used to provide rigidity for driving the PVC pipe. Sections of pipe were added and driven in this manner until refusal to advance occurred. Advancement ranged from 2 m to 8.3 m.

During the first phase, nests of two piezometers were installed at locations where the maximum advancement of a piezometer was greater than 3 m. Prior to each location the first piezometer was advanced as far as possible (i.e. refusal to advance). During advancement the tailings below the water table liquefy around the piezometer allowing relative ease in advancement. The maximum advancement varied from site to site depending on depth to the water

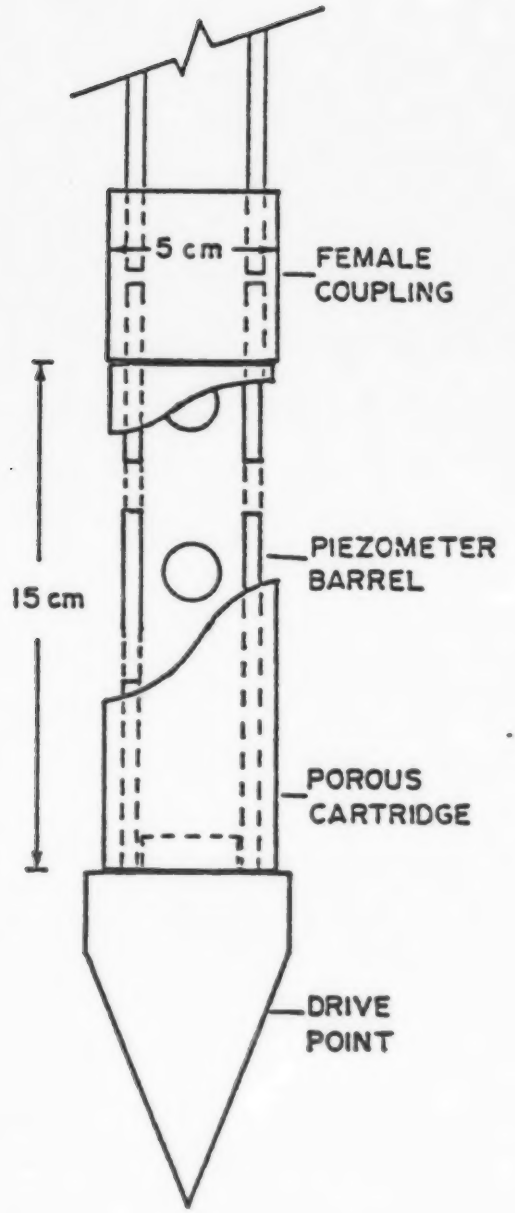


FIGURE 3 PIEZOMETER TIP

table and the grain-size of the tailings. The deeper the water table the more difficult the advancement because the vibration of the pipe was primarily sideways. The more coarse (sandy) the tailings, the more difficult the advancement as the tailings do not liquefy but in fact compact making advancement impossible. Small oxidized zones (hardpan) of tailings were also encountered at various depths depending on depositional history and water table location, making advancement very difficult.

After the deeper piezometer was installed a shallow piezometer was installed at between 1.5 - 2 m below ground surface. This was done during the first phase to examine the vertical gradients at these locations prior to the more detailed second phase of investigation. This was also done to establish preliminary pH and electrical conductance patterns. Eight two-nested piezometer locations, one three-nested and five single piezometer locations were established the first phase of the study.

During the second phase of study, piezometers were installed both by hand and by drilling methods. A number of multiple piezometer nests were installed by hand, using the above described techniques, with a vertical spacing of a approximately 1.5 m between piezometers at each nest.

In areas within the tailing where piezometers could not be installed by hand, a drill rig was utilized to install the piezometers. This was done by using hollow stem augers to drill to just above the location where the piezometer was to be installed. The piezometer was then driven by hand 0.5 -1.0 m below the lead augers to allow for an installation of the piezometer in relatively undisturbed tailings.

Piezometers installed in the clay underlying the tailings were slotted (#10 slot) Schedule 40 PVC pipe ranging in length from 0.6 m to 3 m. These piezometers were installed inside the hollow stem augers and were gravel packed with 0.6 cm (¼ In.) washed p-gravel and a bentonite seal placed above the gravel pack. Boreholes in the clay were backfilled with a combination of clay cuttings and bentonite up to the tailings/clay interface to prevent possible migration of contaminants from the tailings down the borehole. During emplacement of the bentonite seal, water was pumped down the inside of the piezometer casing and forced up through the gravel pack to remove possible tailings material which may have entered the inside of the augers during drilling.

2.4 Water Level Monitoring

Water levels were monitored upon installation of each piezometer and during the time of the field study. Routine monitoring was done to determine when the water levels had stabilized or reached equilibrium after installation or after pumping.

Water levels were measured, using a coaxial cable electric probe, as depth below the top of the uncapped piezometer pipe us. The tops of these pipes were surveyed relative to a local benchmark. The elevation of the local benchmark relative to geodetic is only approximate but is within 0.5 m of geodetic and is sufficient for this phase of study. The survey loop was closed back to the local benchmark with a closure of less than 2 cm.

From monitoring water level data, groundwater flow directions and hydraulic gradients can be established over the tailings area. This information combined with hydraulic conductivity information discussed in the next section can provide an estimate of groundwater fluxes and velocities within the tailings.

2.5 Hydraulic Conductivity Testing

Hydraulic conductivity tests were conducted at most piezometers within the tailings. Hydraulic conductivities of the tailings material surrounding each piezometer were determined using a method known as the Hvorslev rising head test (Hvorslev, 1951).

The water column in a piezometer pipe is pumped out and the rate of inflow of water is measured (i.e. depth to water) during the recovery of the water level back to equilibrium. Knowing this rate of recovery and the shape of the piezometer (i.e. length and diameter of the

water intake zone), the hydraulic conductivity of the tailings in the immediate vicinity of the piezometer can be determined.

Although this method measures the horizontal hydraulic conductivity, the lengths of the piezometer tips are short (13 cm) should give a reasonable approximation of the vertical hydraulic conductivity even though the tailings material is layered. By testing a number of piezometers within the tailings, the spatial variability in the hydraulic conductivity can be determined and representative values for the various textural types (i.e. various grain sizes) can be estimated.

The data were analyzed with the Hvorslev (1951) method using the equation:

$$T_o = \frac{\pi r^2}{F K}$$

where r is the radius of the piezometer (L), F is a factor that depends on the shape and dimensions of the piezometer intake (L), K is the hydraulic conductivity in the immediate vicinity of the piezometer (L/T), and T_o is the basic time lag, which is the time that would be required for complete equalization of the head difference if the original rate of inflow into the piezometer were maintained.

To interpret the field recovery data the value of T_o is obtained from

the relative water level versus time graph and the hydraulic conductivity is determined using the following equation:

$$K = \frac{r^2 \ln (L/r)}{2L\, T_o}$$

where r is the radius of the piezometer (L), and L is the length of the piezometer (L). L/r 8 must be satisfied to use this equation.

Results of hydraulic conductivity testing are presented and discussed in Section 3.4.

2.6 Electrical Conductance and pH Measurements

Measurements of pH and electrical conductance were made in the field on piezometer water samples to examine the variability in gross water chemisty within the tailings and at surface water locations surrounding the tailings. These measurements provide an initial indication of the variability of water chemistry across the site to aid in understanding the general groundwater flow system and help establish a sampling program for more detailed chemical analyses.

Water was pumped from piezometer pipes using a peristaltic pump or a hand-operated vacuum pump. Water was removed generally to a depth just above the piezometer tip. Measurements of electrical conductance and pH were done during pumping to determine if the water chemistry appeared to be stablilized. The pH probe was

routinely calibrated against pH 7 and/or 4 buffers to ensure accuracy. Measurements were taken from initial volumes of water pumped, intermediate volumes, and late volumes to determine the variation in the parameters measured. Electrical conductance and pH were measured immediately after a sample was obtained and in several cases the sample was allowed to stand for a period of time to determine if the chemistry of the water sample was changing over time when exposed to the atmosphere.

Results are presented and discussed in Section 3.5.

3.0 RESULTS AND DISCUSSION

3.1 Geophysical Interpretation

Seismic Survey

The seismic refraction survey was conducted along three lines as shown in Figure 5 prior to the implementation of drilling (figure 4). It was hoped that these lines would provide representative cross-sections across the site, or at least determine the degree of variability in thickness and depths of the different geologic units.

A sledge hammer was used as a source for a seismic pulse (ground vibration). The travel time of the pulse between the source and geophones was measured with a 12-channel signal enhancement seismograph (Nimbus 1210F).

The geophones were spaced at 15 metre intervals along each line. Line S1 (Figure 5) was surveyed with six 165 metre spreads of 12 geophones, with 2 geophones (15 metres) overlapping between spreads. Lines S2 and S3 consisted of one 115 metre spread each. Five pulses or shotpoints were used on each spread, one in the middle, one at each end, and one approximately 60 metres off each end. At the ends of each spread, short (2.5 or 4 metre geophone spacing) spreads were used to give near surface velocities.

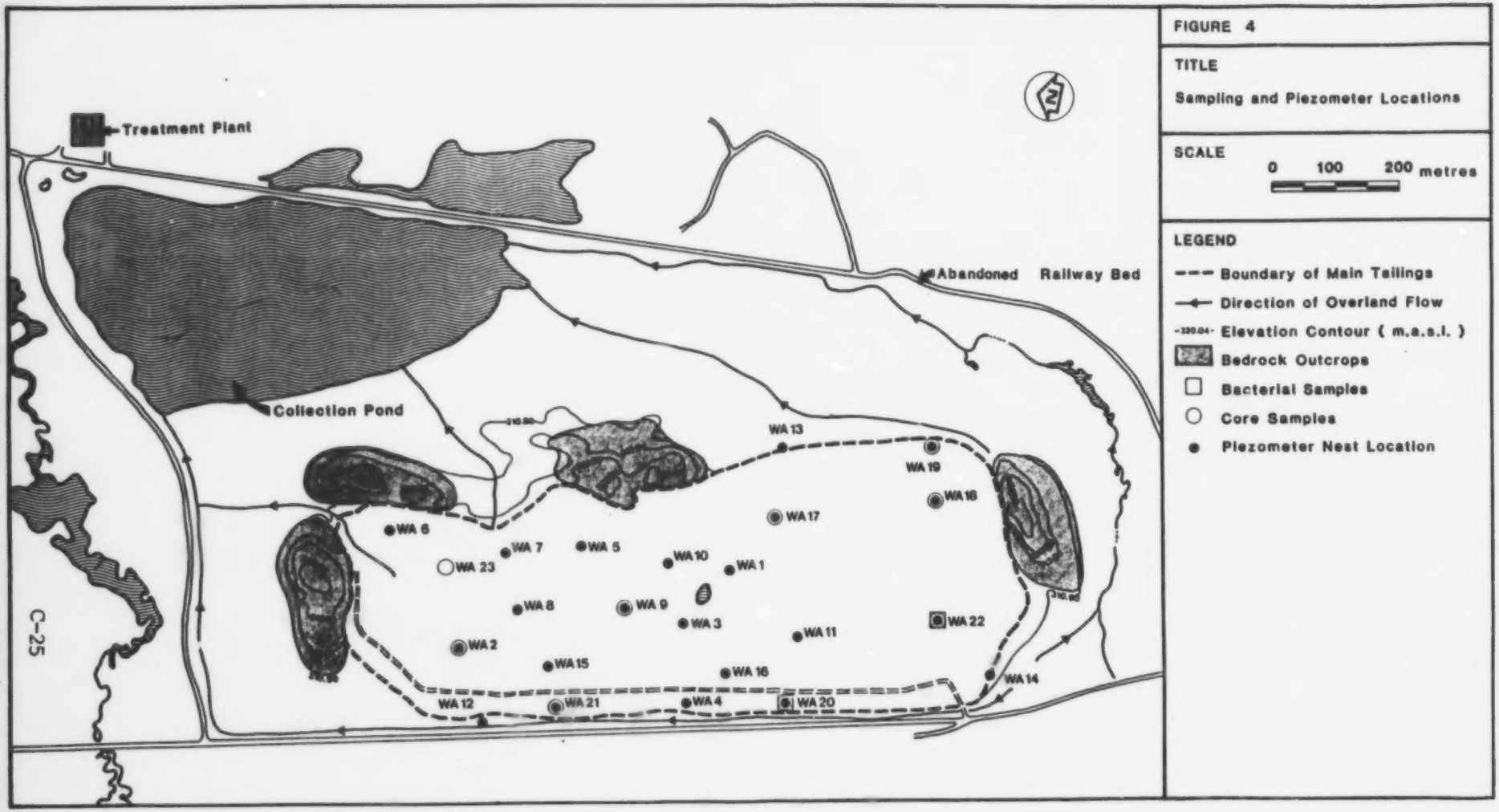


FIGURE 4

TITLE

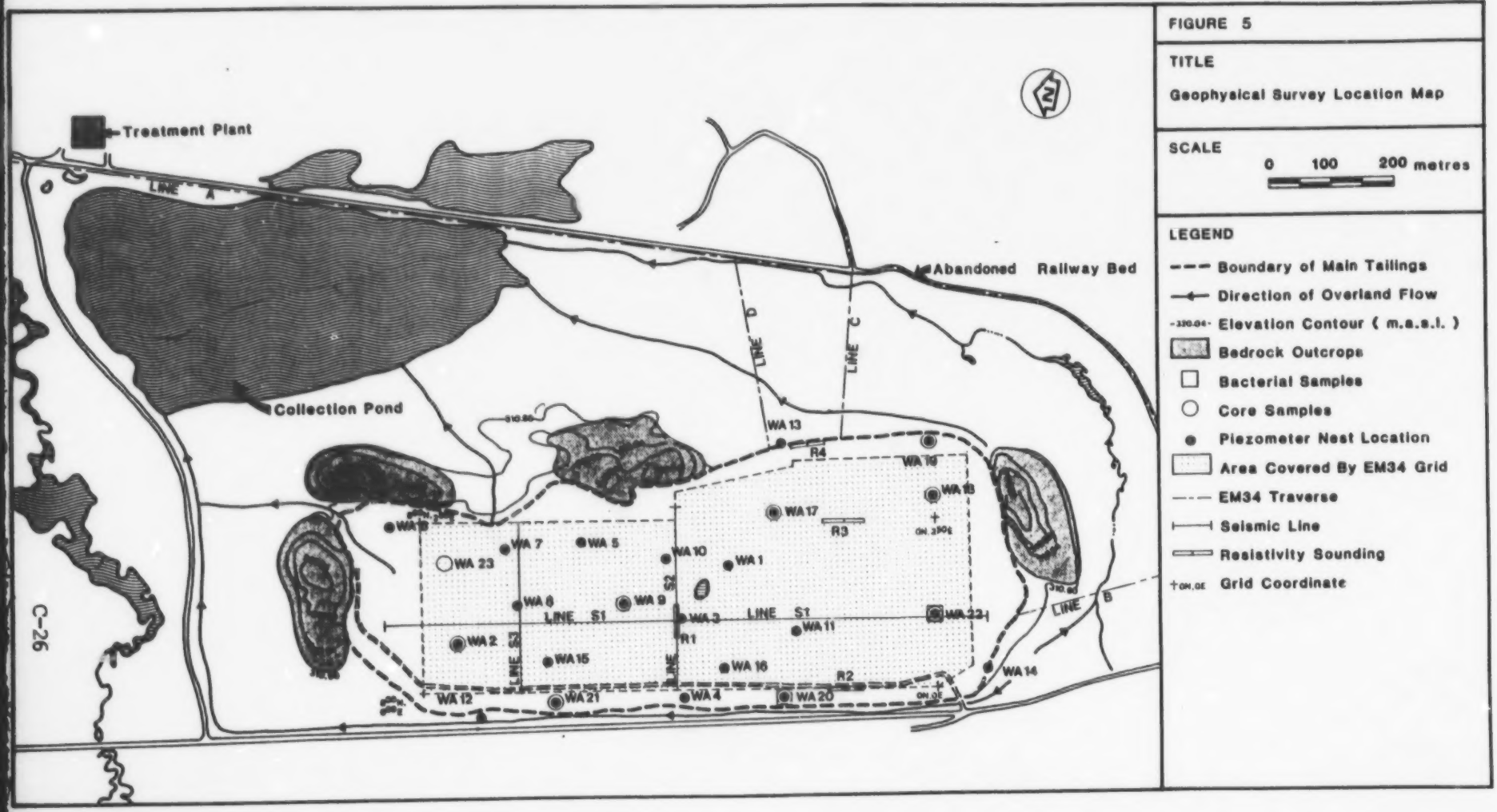
Sampling and Piezometer Locations

SCALE

0 100 200 metres

LEGEND

- Boundary of Main Tailings
- Direction of Overland Flow
- Elevation Contour (m.a.s.l.)
- Bedrock Outcrops
- Bacterial Samples
- Core Samples
- Piezometer Nest Location


Treatment Plant
LINE A
Abandoned Railway Bed
Collection Pond
LINE D
LINE C
WA 13
R4
WA 19
WA 18
WA 17
R3
WA 7
WA 5
WA 10
WA 1
WA 23
WA 8
WA 9
LINE S1
WA 3
LINE S1
WA 22
WA 11
R1
WA 2
WA 15
LINE S2
LINE S2
WA 16
R2
WA 14
WA 12
WA 21
WA 4
WA 20
LINE B
N
FIGURE 5
TITLE
Geophysical Survey Location Map
SCALE
0 100 200 metres
LEGEND
Boundary of Main Tailings
Direction of Overland Flow
Elevation Contour (m.a.s.l.)
Bedrock Outcrops
Bacterial Samples
Core Samples
Piezometer Nest Location
Area Covered By EM34 Grid
EM34 Traverse
Seismic Line
Resistivity Sounding
Grid Coordinate

Seismic Data Quality

An indication of the data quality is the error in reciprocal times for each spread. A reciprocal time error is the difference in times required for the pulse to travel from the end shot to the furthest geophone in either direction. The error was less than 2 milliseconds, indicating consistent data.

Under most conditions a hammer source can yield refracted arrivals from depths up to approximately 30 m. Bedrock depths towards the south end of the site were at the limit of the hammer range, and consequently the bedrock signals were weak at times in this area. One traverse across the south end of the site was cancelled due to equipment problems.

Seismic Results

The interpretation of the seismic refraction data, shown as a series of cross-sections in Figures 6 and 7 was made by the "delay time" technique presented by Redpath (1976). Over most of the area, 4 layers can be identified and they are described below:

LAYER 1 is a discontinuous surface unit with a seismic velocity of 300 metres per second (m/sec). This layer represents unsaturated and very poorly consolidated tailings or fill.

LAYER 2 with a velocity on the order of 600 m/sec (varying 20 percent over the site) represents saturated tailings. This velocity is at

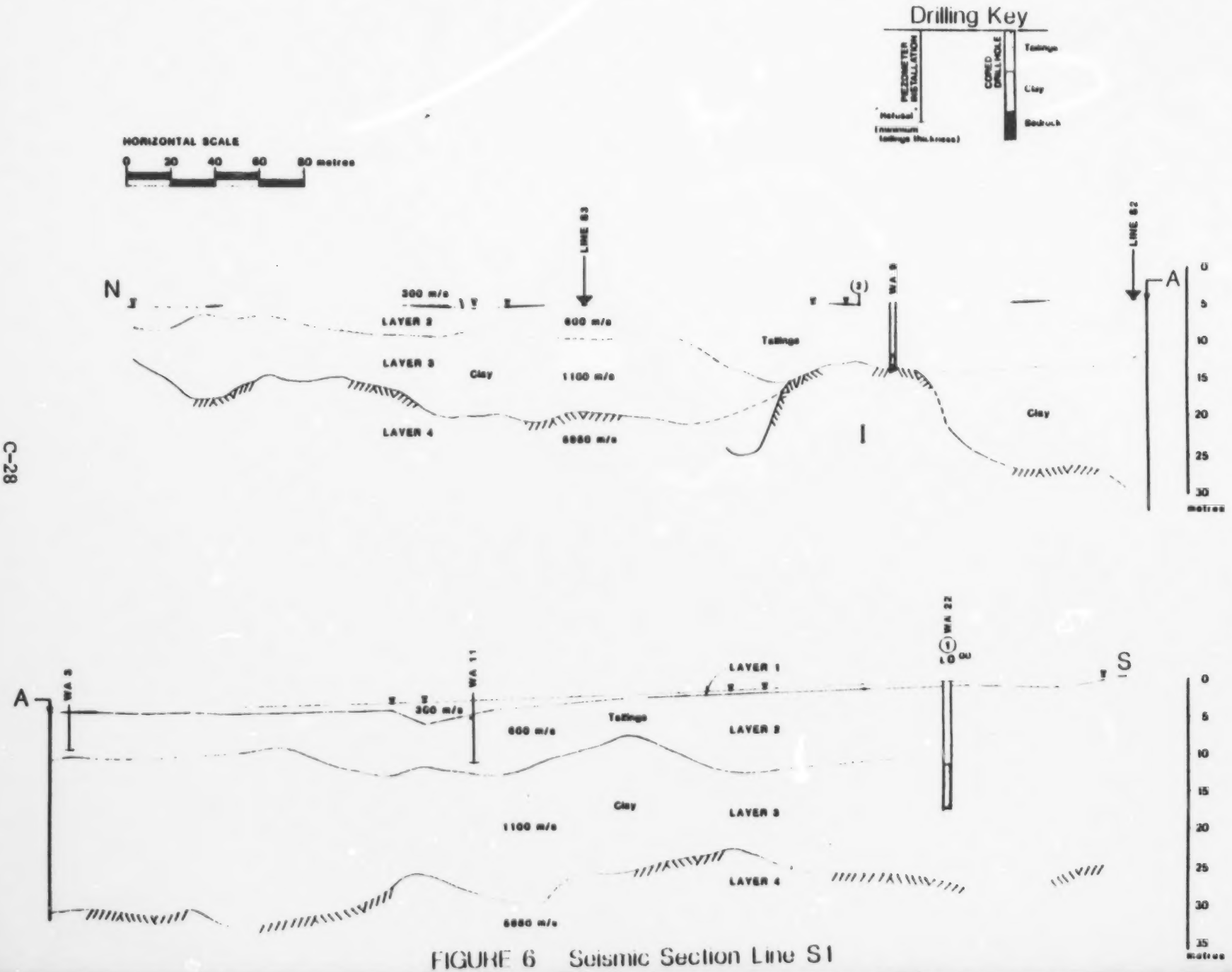


FIGURE 6 Seismic Section Line S1

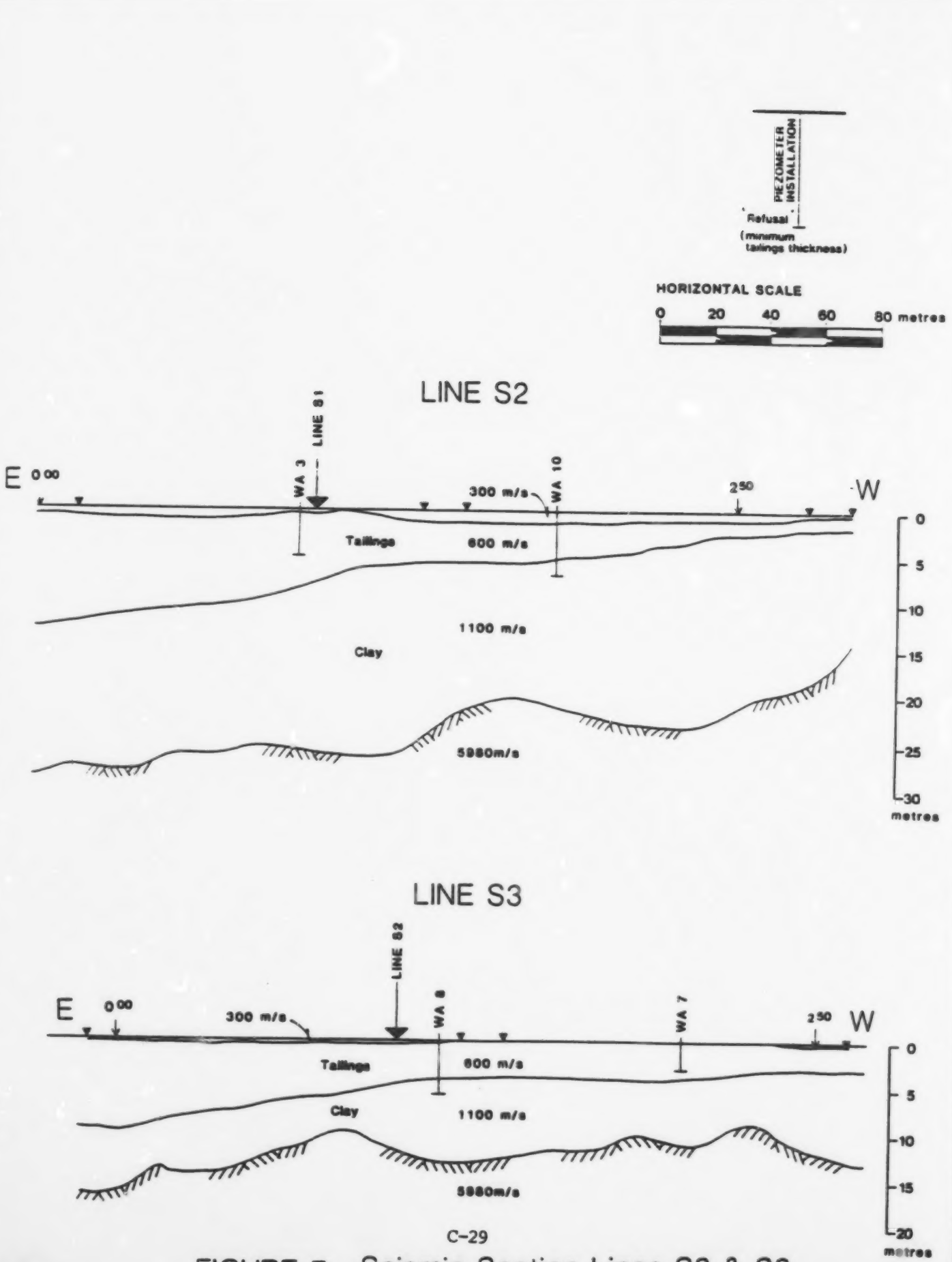


FIGURE 7 Seismic Section Lines S2 & S3

the lower extreme of the values attributed to a saturated sand by Jakosky (1957). The unit is continuous and varies in thickness from 2 to 10 m over the site.

LAYER 3 is identified as a clay layer based on drilling results. The seismic velocity is 1100 (+-10%) m/sec and the thickness varies from 21 m to less than 2 m The elevation of the top of Layer 3 varies by 5 m over the site.

LAYER 4 is bedrock and has a seismic velocity of 5980 (+-13%) m/sec. Bedrock surface is irregular, with over 15 m of total relief across the site.

The most prominent bedrock feature is a local high encountered at location "I" on line S1 (Figure 6). The edges of this high are too steep to resolve with seismic refraction methods and are therefore represented by dashed lines.

Comparison of Seismics and Drilling

The control for the seismic survey has two forms. The best control consists of the 2 cored drillholes, on or very near the seismic lines, denoted WA9 and WA22 on Figure 5. The second type of control consists of piezometer installations. These were installed by hand to "refusal" which, based on correlation of the drilling, was usually at or just above, the clay interface. The piezometer installations give a minimum depth to the clay because at some locations clay was deeper than the maximum advancement of the piezometer.

Many of the drillholes and piezometer installations on site are too far from the seismic lines to be useful in evaluating the seismic interpretation, considering the layer thicknesses variability.

The depth to the top of Layer 3 (clay), as interpreted from the seismics, is within 1.0 m of observed values from drillholes and within 1.5 m of refusal (or deeper) at all applicable piezometer installations. The 1.5 m of clay encountered at WA9 was missed in the seismic interpretation because it forms a hidden layer between bedrock and the tailings.

Only WA9 is a reliable measure of the bedrock depth, and it is within half a metre of the interpreted value. All other drillholes that reach bedrock are too far from the seismic lines to be correlated.

ELECTROMAGNETIC SURVEY (EM)

The ground conductivity of the site was measured using a Geonics EM34-3 units. Reading were taken at approximately 600 stations in the area shown in Figure 5. Stations were spaced at 20 m intervals along lines 25 m apart.

The transmitter-receiver separation was 20 m at all stations. Measurements were made in both the horizontal (H) and Vertical (V) dipole modes. Effective penetration depths were 15 and 30 m respectively.

EM Data Quality

A base station was read at the beginning and end of each day, to check for possible instrument drift. In both the horizontal and vertical modes these repeated readings did not vary by more than 1 millimho per metre (mmho/m), or 2% of full scale.

Readings were influenced considerably by sharp variations in bedrock depth. When bedrock is shallow (i.e. under 4 m) and changing elevation over a short distance, "edge effect" can introduce spurious readings. To minimize these effects the data were smoothed using a 5 point running average.

EM Results

A contour plot of the raw EM34-20H data (Figure 8) is dominated by shallow bedrock under the northern half of the site. In an attempt to isolate the tailings electrical conductivity variations, from those created by changes in bedrock depth, the data were corrected on the basis of a two layer model using equations presented by McNeill (1980). A completely descriptive model of the site would have a minimum of three layers over bedrock. Since readings in only the two dipole orientations were available at each station, only two model parameters could be varied.

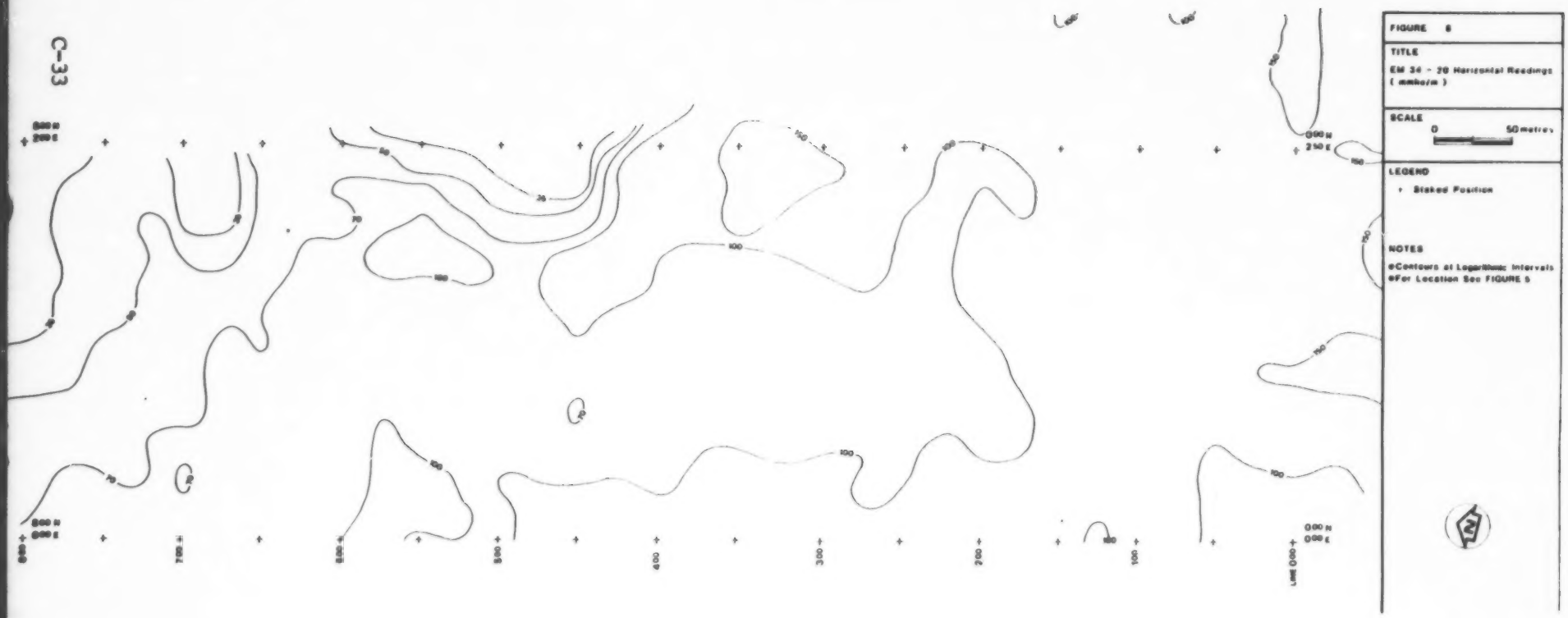


FIGURE 6
TITLE
EM 34 - 20 Horizontal Readings
(mmho/m)
SCALE
0
50 metres
LEGEND
Staked Position
NOTES
•Contours at Logarithmic Intervals
•For Location See FIGURE 5
N

The thin layer of unsaturated tailings in the north portion of the site can be neglected at these coil spacings. The saturated tailings are extremely conductive relative to the underlying clay and the bedrock. Consequently, the stratigraphy can be reasonably approximated as a two layer case, with a surface layer (tailings) of variable conductivity and thickness, overlying a 0.1 mmho/m conductivity material that extends to infinity. The thickness and conductivity for the upper layer of the model were then varied to fit the horizontal and vertical dipole responses at each station. Results are shown in Figure 9 and 10.

Figure 9 shows an apparent electrical conductivity for the tailings. The contours are logarithmic, and appear to show two zones of high electrical conductivity. One, marked "II", is at the western edge, and the other, marked "III", is at the extreme south end of the site. The latter may be related to buried metal (ie. old tailings discharge lines) since readings in both dipole orientations were extremely unstable in that region. The northern end of the site, and a central zone, marked "IV", have relatively low conductivities.

The conductivities determined for the tailings range from 100 to over 400 mmho/m. In comparison, the conductivity of a clean, saturated sand is typically 5 to 10 mmho/m, while clay may range from 20 to 50 mmho/m.

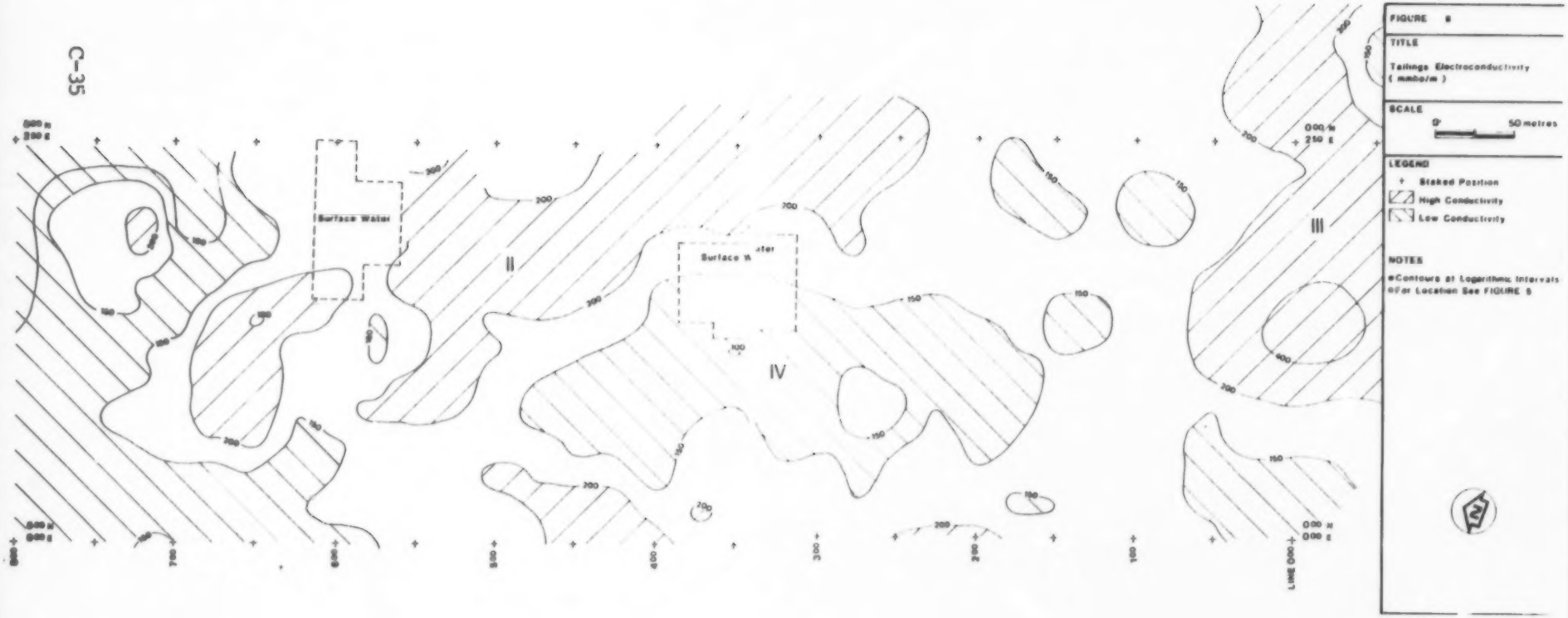

Surface Water
II
Surface Water
IV
III
FIGURE 8
TITLE
Tailings Electroconductivity
(mmho/m)
SCALE
0 50 metres
LEGEND
Staked Position
High Conductivity
Low Conductivity
NOTES
•Contours at Logarithmic Intervals
•For Location See FIGURE 9

FIGURE 10
TITLE
Isopach Thickness
Based On Em
SCALE
0
50 Metres
LEGEND
Stake Position
NOTES
Contour Units Are
Noted In Metres
For Location See FIGURE 9
LINE 000 +
000 N
000 E
100 +
200 +
300 +
400 +
500 +
600 +
700 +
800 +
Surface Water
Surface Water
000 N
200 E

Figure 10 shows apparent thickness of the tailings, derived from the two layer modeling. The general trend shows the tailings thinning from 15 to 20 m in the south to less than 5 m in the north. The extremely thin tailings indicated near "III" is probably also attributable to metal in the tailings.

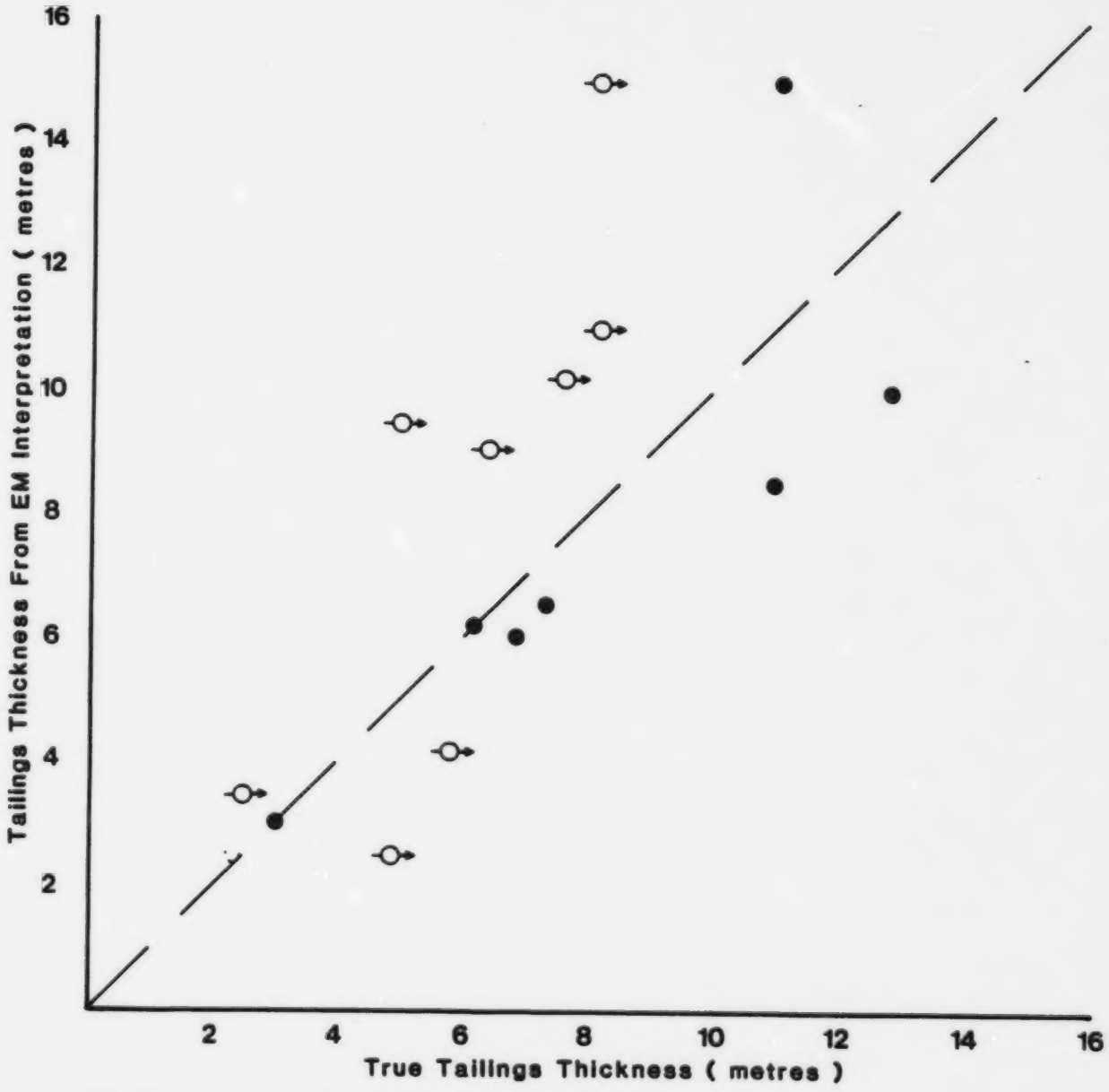
Comparison of Electromagnetics and Drilling

Figure 11 is a plot of the the observed versus calculated tailings depths. The points scatter about the 45 degree line with a correlation coefficient of .667. The potential error in the depth contours are 25 to 30 percent.

A similar plot was attempted to relate the groundwater electrical conductivities measured in the sampling piezometers to the apparent tailings conductivities calculated from the geophysical survey. However the water conductivities varied so much with depth at most of these holes that no meaningful correlation could be made.

RESISTIVITY SOUNDINGS

Direct current resistivity soundings were used to measure the broad vertical variations in terrain resistivity. A resistivity sounding is normally presented in a log-log plot of apparent resistivity in ohm-m versus electrode spacing in metres. However, to keep units consistent with the EM data, the results are presented here in terms of electrical conductivity.



NOTE : ● True Thickness From Drillhole
⊸ Minimum Thickness From Piezometer Installation

FIGURE 11 Electromagnetics vs Drilling Results (Tailings Thickness)

Resistivity Results

The conventional resistivity survey is supplementary to the EM results and consequently the interpretation is based on the appearance of the sounding curves and not on a model inversion. Moreover, the curves show evidence of lateral electrical conductivity variations that can not be modelled by standard routines.

At locations R1 and R3 (Figure 5), the electrical conductivity of the tailings increases slightly with depth over the top 3-4 metres (see Figure 12). The tailings electrical conductivity at R1 is slightly greater than at R3 and the bedrock shallower (i.e. 7-9 m at R1 versus 20-23 m at R3).

At R2 the tailings electrical conductivity increases slightly with depth near surface (1-2 m). Conductivity decreases to 26 mmho/m from 4 to 15 m (approximately) and the bedrock influences the curve beyond 25-30 metres.

The resistivity results correlate well with the EM interpretation, and support the two layer assumption used in the EM modelling.

General Site Description From the Geophysical Results

Bedrock

The exposed bedrock topography around the site is extremely variable. The seismic data along sections show that the same is true beneath the site, and consequently any extrapolation of the interpretation beyond the vicinity of the sections is suspect.

Bedrock elevation decreases to the south-southeast across the site. At least two, and possible three ridges trending northeast-southwest appear to extend from bedrock outcrops to the tailings.

Clay

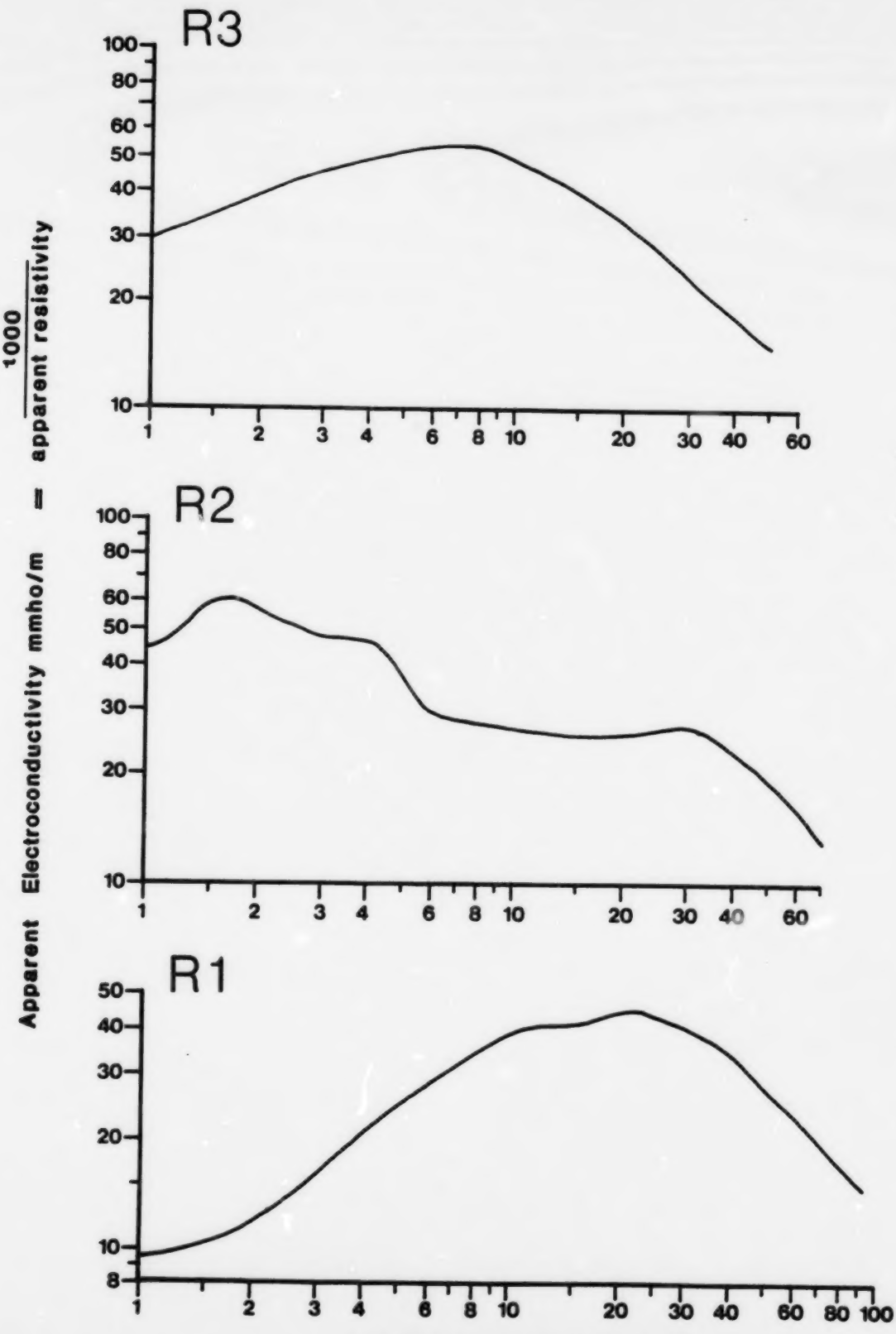
The surface of the clay is moderately irregular as it slopes to the south and west across the site. Its thickness varies from 2 to 20 metres, thinning on bedrock highs. It has a fairly uniform seismic velocity.

The Tailings

The thickness of the tailings varies from 2 m to about 15 m. The thickness increases to the south and west, filling any depressions in the surface of the clay. The seismic velocity of the tailings is suprisingly

FIGURE 12

"Electroconductance" (Resistivity) Soundings Of Tailings



uniform and more typical of unsaturated materials. The electrical conductivity is variable but always high. The northern and south-central part of the site are of low electrical conductivity and the east-central and southern areas have high electrical conductivities.

OFF SITE RESULTS

Four EM34 traverses were run about the south and west perimeter of the site (Figure 5). Line 'A' is along the old railroad bed east of the site. Stations on this line were read with the 20 m vertical, and the 10 and 20 m horizontal modes at 50 m intervals. Three lines (B to D) extend radially from the site. These were read at a 20 m interval with a horizontal coil orientation at 10 and 20 metre coil separations.

On line A (Figure 13) the 20 m vertical mode reading is strongly influenced by bedrock shallowing. The 10 and 20 m horizontal responses show a decrease in conductivity with depth, again most probably a bedrock related trend. Where bedrock deepens, the readings at all three penetration depths are in the 10 - 35 mmho/m range (typical unconsolidated material conductivities), indicating little vertical variation in conductivity. The only area of high readings is related to a power line.

Line B responses are not plotted since most of the readings were

either extremely unstable or off scale. This is attributed to pipes observed on surface, and/or clay covered pyrite piles reported to be in the area.

Line C (Figure 14) shows a strong lateral decrease in conductivity moving from the tailings pile to west of the tailings. From the road and beyond, the readings remain fairly consistent.

There is a consistent decrease in conductivity with depth at all stations. Between the tailings and the road the plots of the 10 and 20 m results are parallel, indicating some bedrock influence on both. It is impossible to distinguish, with two EM readings, between a lower conductivity value due to a decreasing contamination gradient above bedrock, or to a shallowing of the bedrock. East of the road the values at the two spacings are fairly independent. The 10 m spacing values indicate an overburden conductivity of 25 to 40 mmho/m, suggesting either a high clay content for the material, or above normal water conductivity.

Line D shows the same trends as Line C, except for a drop in the readings just beyond the tailings and followed by another increase. This is probably a bedrock effect caused by the knoll to the north extending under the surface material.

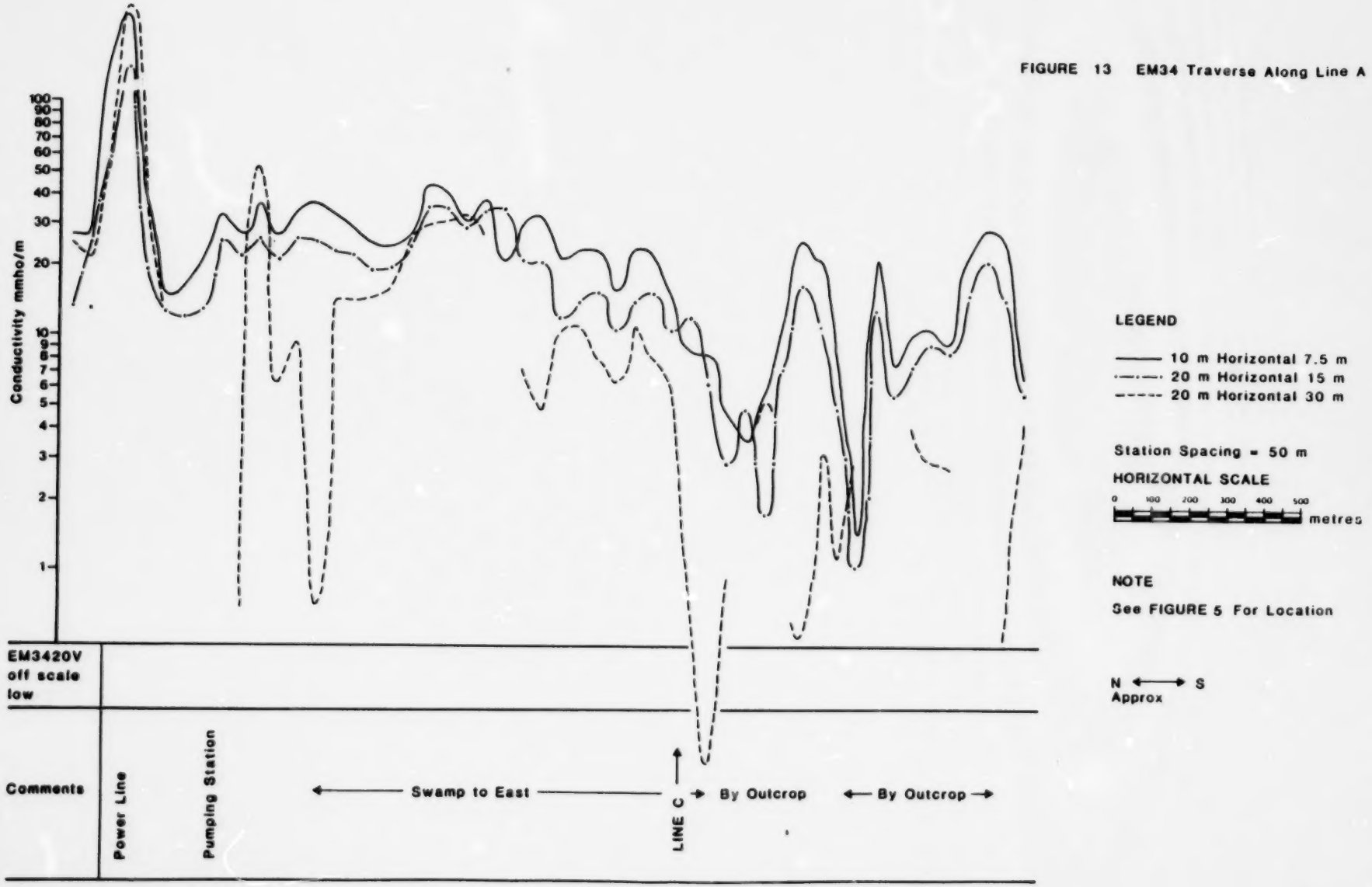
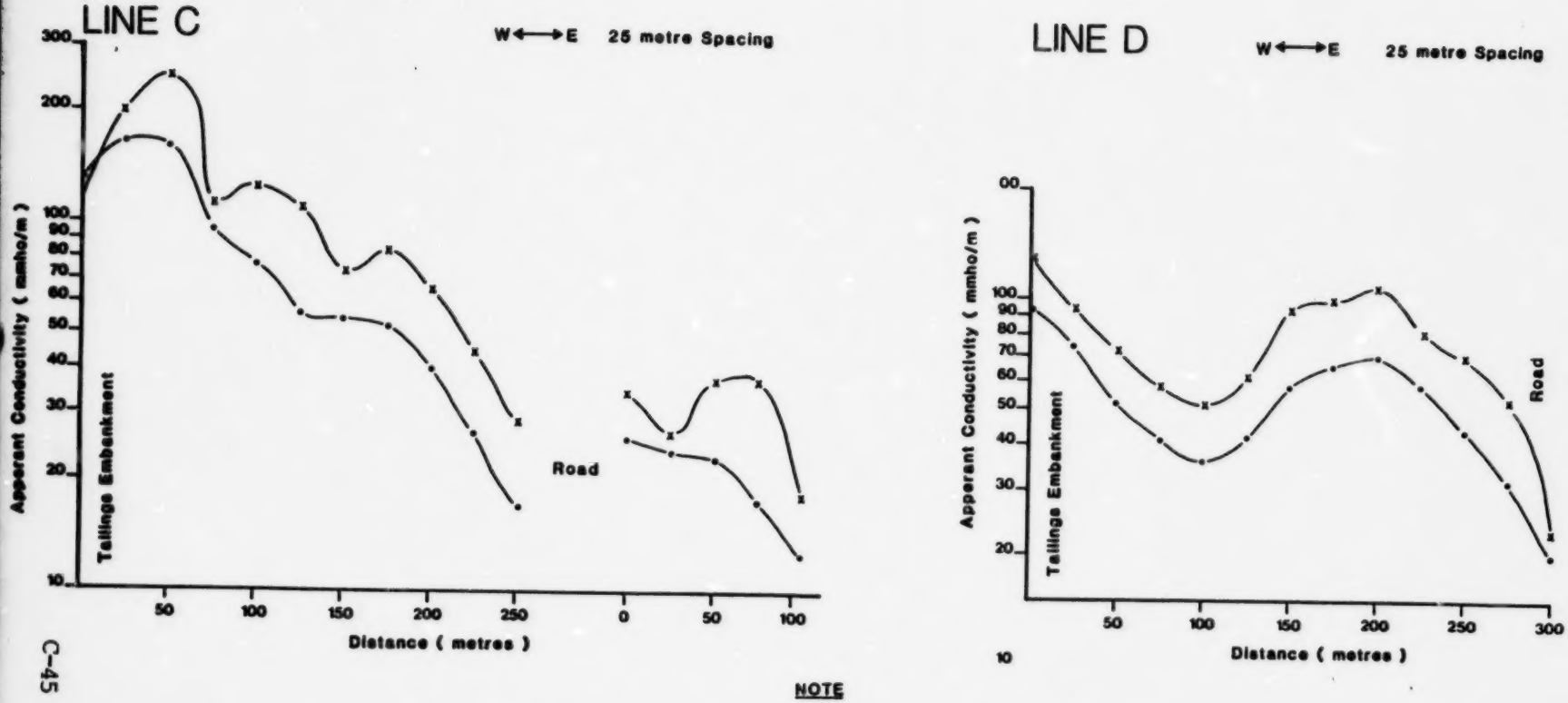


FIGURE 13 EM34 Traverse Along Line A



NOTE

20 m Horizontal

10 m Horizontal

See FIGURE 6 For Location

FIGURE 14 EM34 Traverse

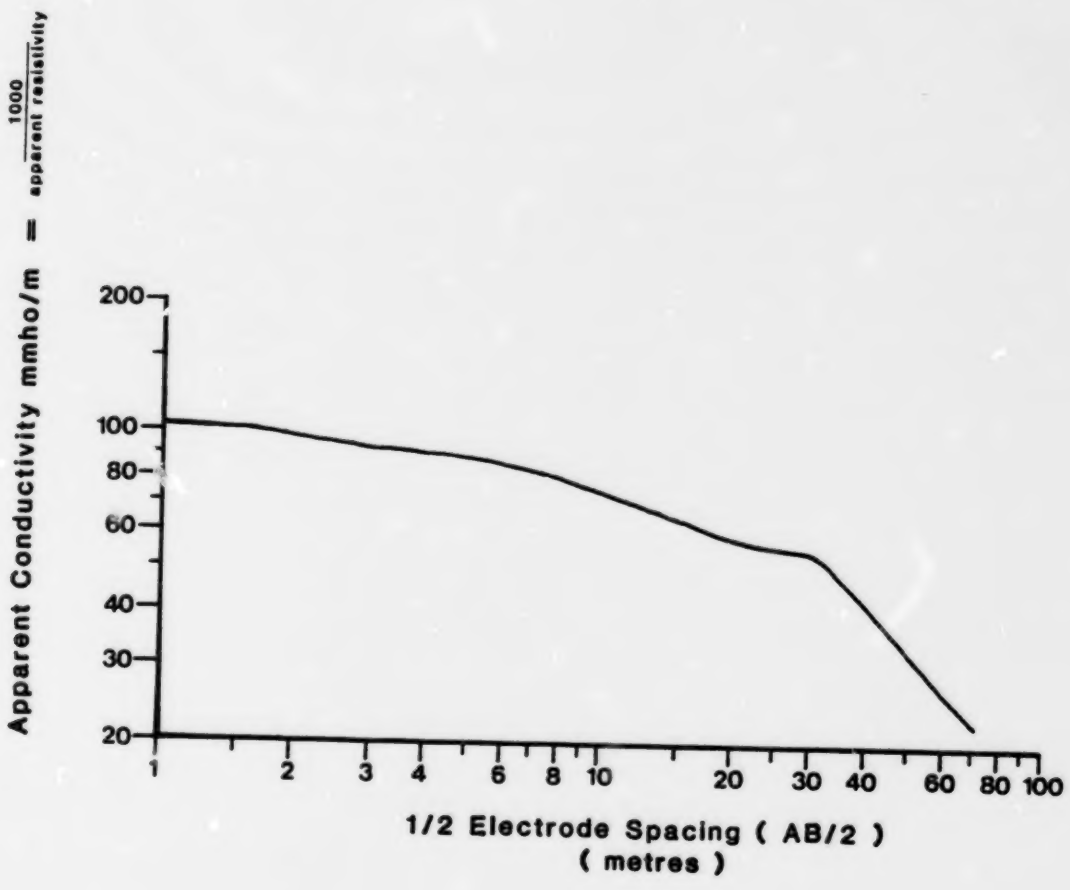


FIGURE 15 "Conductivity" (Resistivity) for R4 Soundings Off Tailings

Resistivity sounding R4 (Figure 15), lies between lines C and D. It shows the conductivity decreasing with depth from 110 mmho/m to 60 mmho/m. Bedrock influences the plot at depths of 25-30 m, implying a fairly deep valley between exposed bedrock highs to the north and south.

3.2 Solid Sampling

Solid sampling was performed at nine locations (Figure 4), six of the locations were on top of the main tailings area while three of the locations were on the bench area of the tailings dam.

The method of sampling discussed in Section 2.2 proved to be very successful in recovery of the tailings solids and the underlying parent material. Sample runs were generally 1.5 m long, however in conditions of very high water content and relatively uncohesive material, long samples would compact in the sample barrel and a full sample could not be collected. When these conditions were encountered the sample length was decreased to 0.75 m each run resulting in full or almost full recovery of the sample. Above the water table full recovery was achieved using a 1.5 m long sample interval in fine and coarse tailings. Below the tailings, full recovery of the underlying clay was also achieved with 1.5 m sample intervals. The contact between the tailings and an underlying thin peat zone directly above the clay was generally well preserved using the long sampling sections.

The samples themselves were relatively undisturbed as the sampler acts similar to the Shelby Tube but has a slightly thicker wall. Horizontal layering was evident in most samples. Along the wall of the sampler there was some curvature of the layers indicating some frictional resistance along the wall. The samples which were most disturbed were the relatively uncohesive tailings with a high water content. These samples, when laid horizontally would run at either end, although the centre of the sample was still relatively undisturbed. A detailed description of the results of solid sampling is given in the borehole logs in Appendix A and a general discussion is given below.

Results of solid sampling indicates the tailings is up to 12.8 m thick in the south portion of the site and is as thin as 3 m in the northwest portion of the site where bedrock outcrops along the edge of the tailings. The general stratigraphy of the site can be seen on cross-sections A-A' through D-D' shown in Figures 18 through 21.

Away from the bedrock outcrops in the northwest, the clay underlying the tailings is up to 10 m thick and consists of primarily a soft varved clay. In the northern portion of the site (i.e. WA2, WA9, WA23) where bedrock is shallow the underlying clay appears to be absent and a clayey silt till 1-2 m in thickness is present above bedrock. The difference between the clay and the clayey silt till is evident from the elevations at which the clay was encountered as shown in Figure 16.

There was a thin layer of peat, generally less than 0.3 m in thickness found between the tailings and the clay at all locations drilled.

3.3 Groundwater Flow System

This section deals with a preliminary discussion of the groundwater flow system, looking at the water table and the vertical gradients within the tailings. A discussion of the groundwater velocities and fluxes is presented in Section 3.5 after the hydraulic conductivities have been discussed.

Water Table

The water table at the Waite Amulet tailings varies from just below ground surface in the north and central portion (i.e. WA1, WA9, WA5) of the site to 5.5 m below ground surface in the southern portion of the site (i.e. WA22, WA18) where the grain size fraction is more coarse. Figure 17 shows the general water table configuration across the tailings area. Water level data obtained to date are found in Appendix B.

Water level data indicate the highest water levels are found in the central portion of the site (WA9, WA1). Water levels are generally high across most of the northeast portion of the site (Figure 17). In the north central and northeast area of the site (i.e. WA8, WA9, WA7,

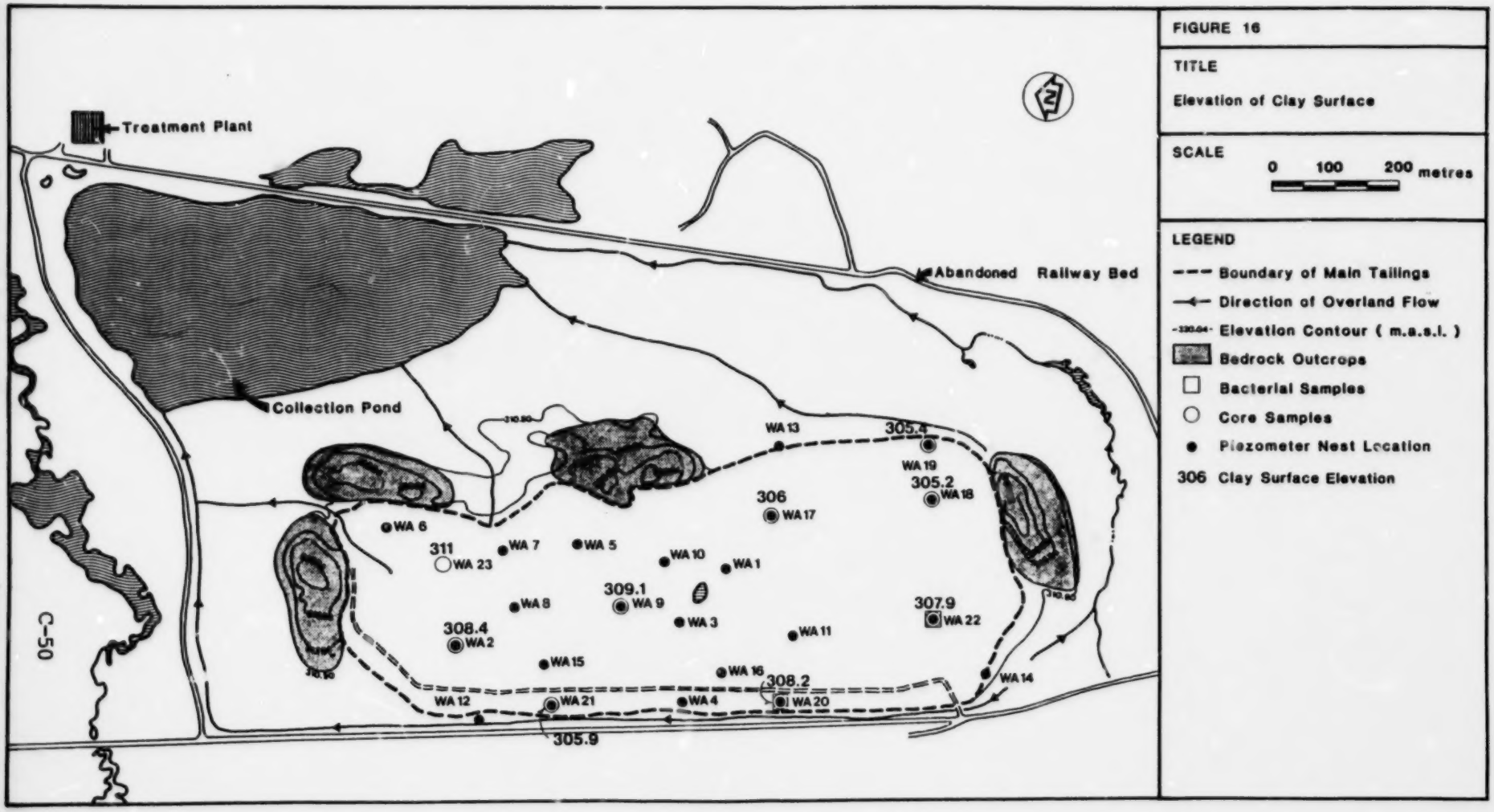


FIGURE 16

TITLE

Elevation of Clay Surface

SCALE

0 100 200 metres

LEGEND

- Boundary of Main Tailings
- Direction of Overland Flow
- Elevation Contour (m.a.s.l.)
- Bedrock Outcrops
- Bacterial Samples
- Core Samples
- Piezometer Nest Location
- 306 Clay Surface Elevation

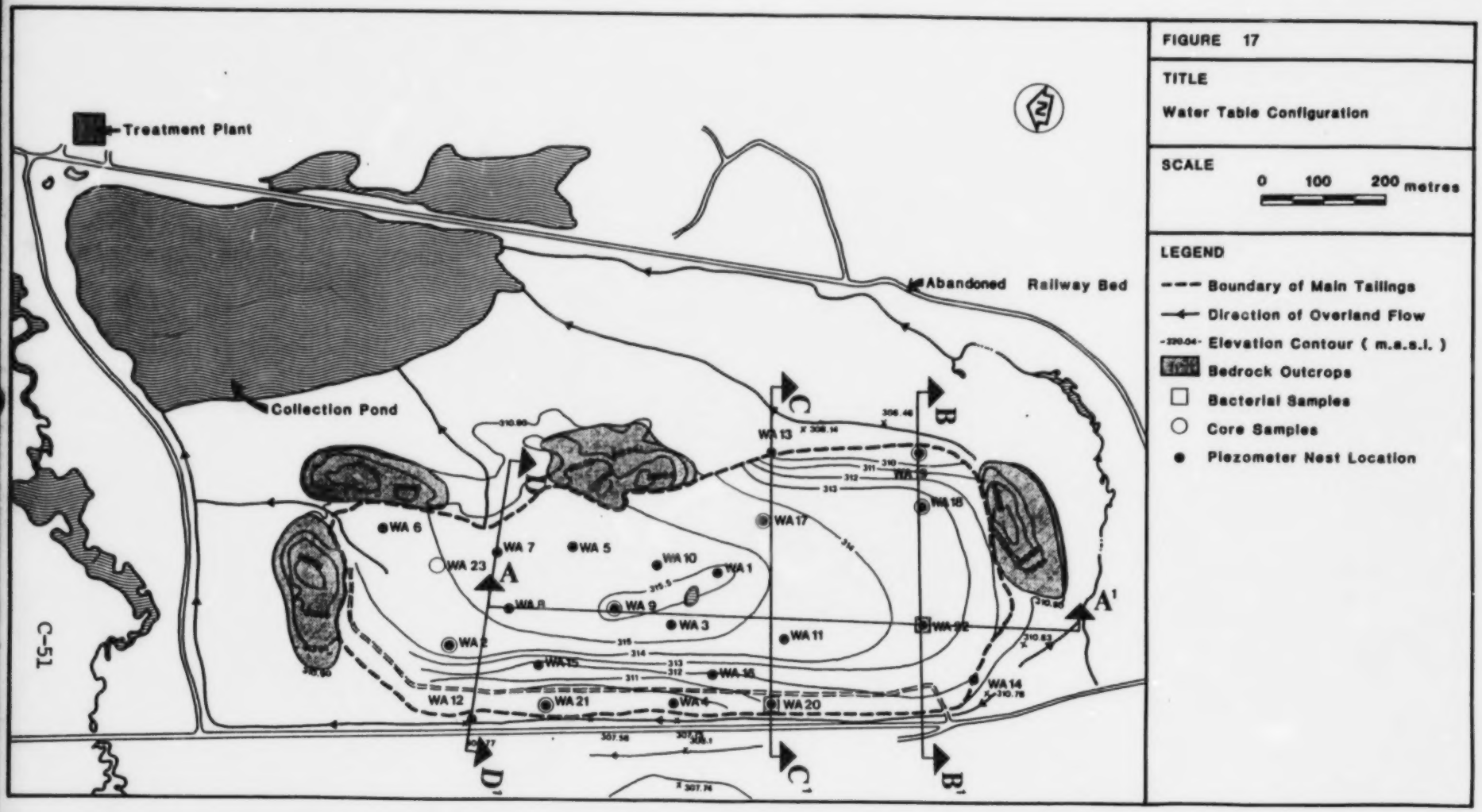


FIGURE 17

TITLE

Water Table Configuration

SCALE

0 100 200 metres

LEGEND

- Boundary of Main Tailings
- Direction of Overland Flow
- 320.04 Elevation Contour (m.a.s.l.)
- Bedrock Outcrops
- Bacterial Samples
- Core Samples
- Piezometer Nest Location

WA5, WA6) the water table slope (i.e. horizontal gradient) is very small except near the valley east of WA7 located between two outcrops. This would indicate groundwater seepage into the valley east of WA7 (as evidenced in the field) but little groundwater seepage into the bedrock in the vicinity of WA6 and WA5. The water table slope is also small across the south portion of the site. The slope is on the order of 0.003 to 0.004 in the south.

Except where the bedrock outcrops along the edge of tailings, the water table slope is quite steep across the tailings dam. The steepest water table slope along the tailings dam is in the northwest (i.e. WA12, WA21) with a gradient on the order of 0.03 to 0.04. This tailings area corresponds to the fine-grained low hydraulic conductivity tailings (see section 3.4) deposited on site. The portion of the tailings dam with the smallest water table slope is in the southwest (i.e. WA14). The gradient is on the order of 0.007. The tailings in this area are the coarsest-grained, highest hydraulic conductivity tailings found on site, allowing for a more rapid movement of water through this area.

Vertical Groundwater Movement

More than one piezometer was installed at most locations to examine vertical water level profiles (vertical hydraulic gradients) as well as water chemistry profiles. Figures 19 through 21 show water level distributions along cross-sections A-A' through D-D' respectively. Figure 2 shows the locations of the cross-sections.

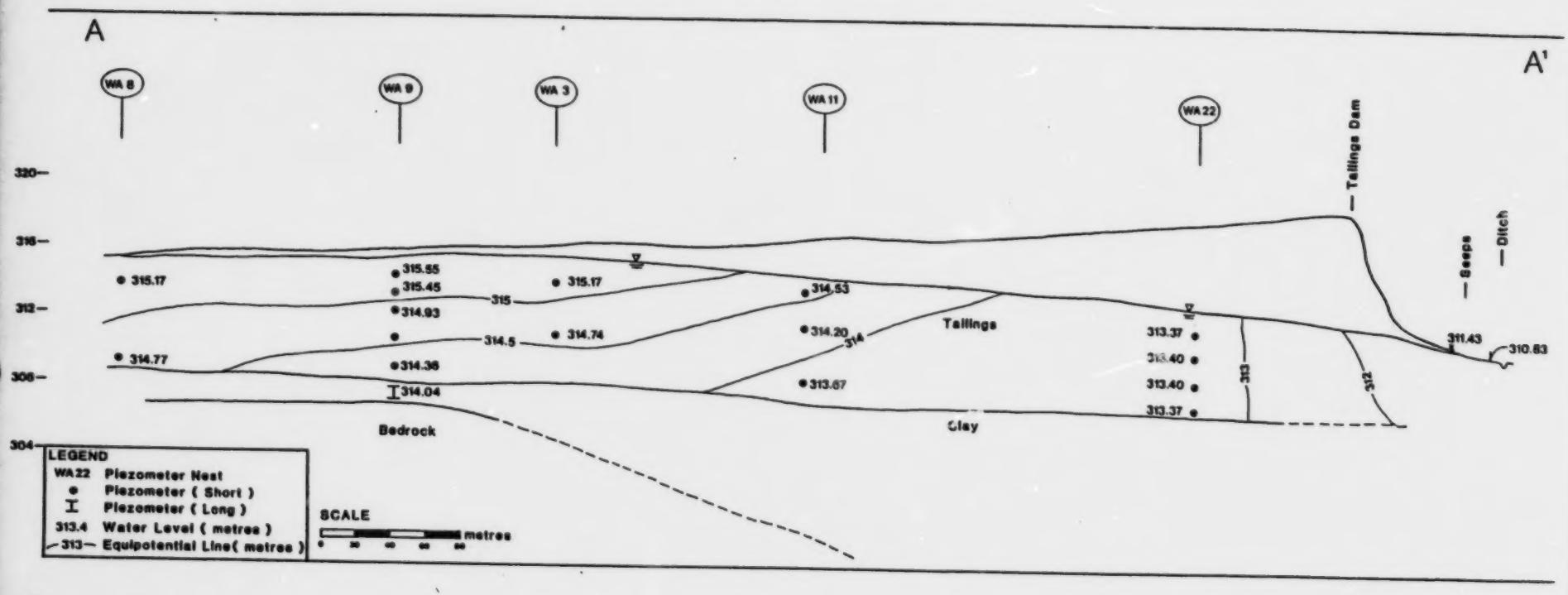
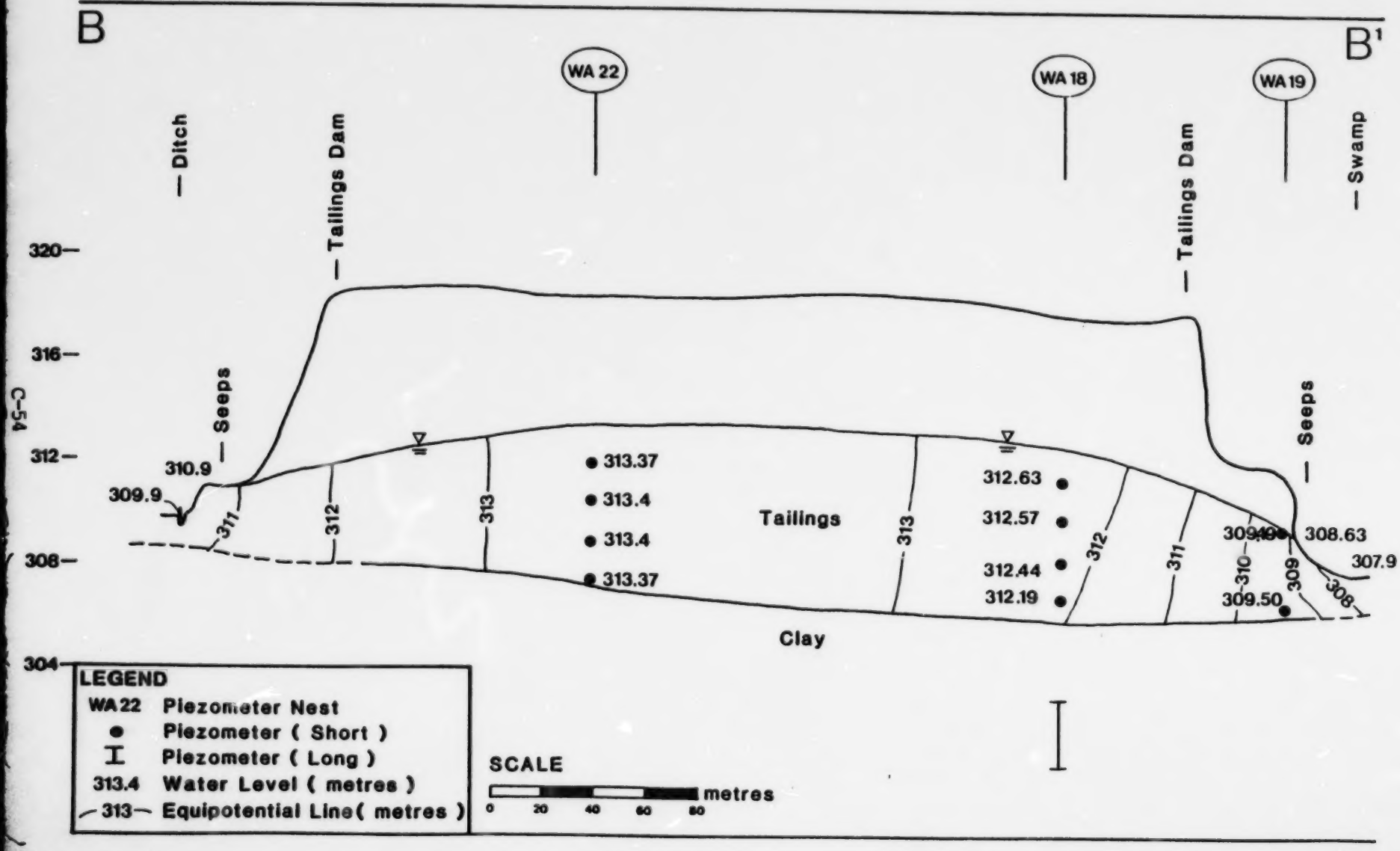


FIGURE 18 WATER LEVEL DISTRIBUTION - CROSS-SECTION A-A'



C-54

FIGURE 12 WATER LEVEL DISTRIBUTION - [illegible]

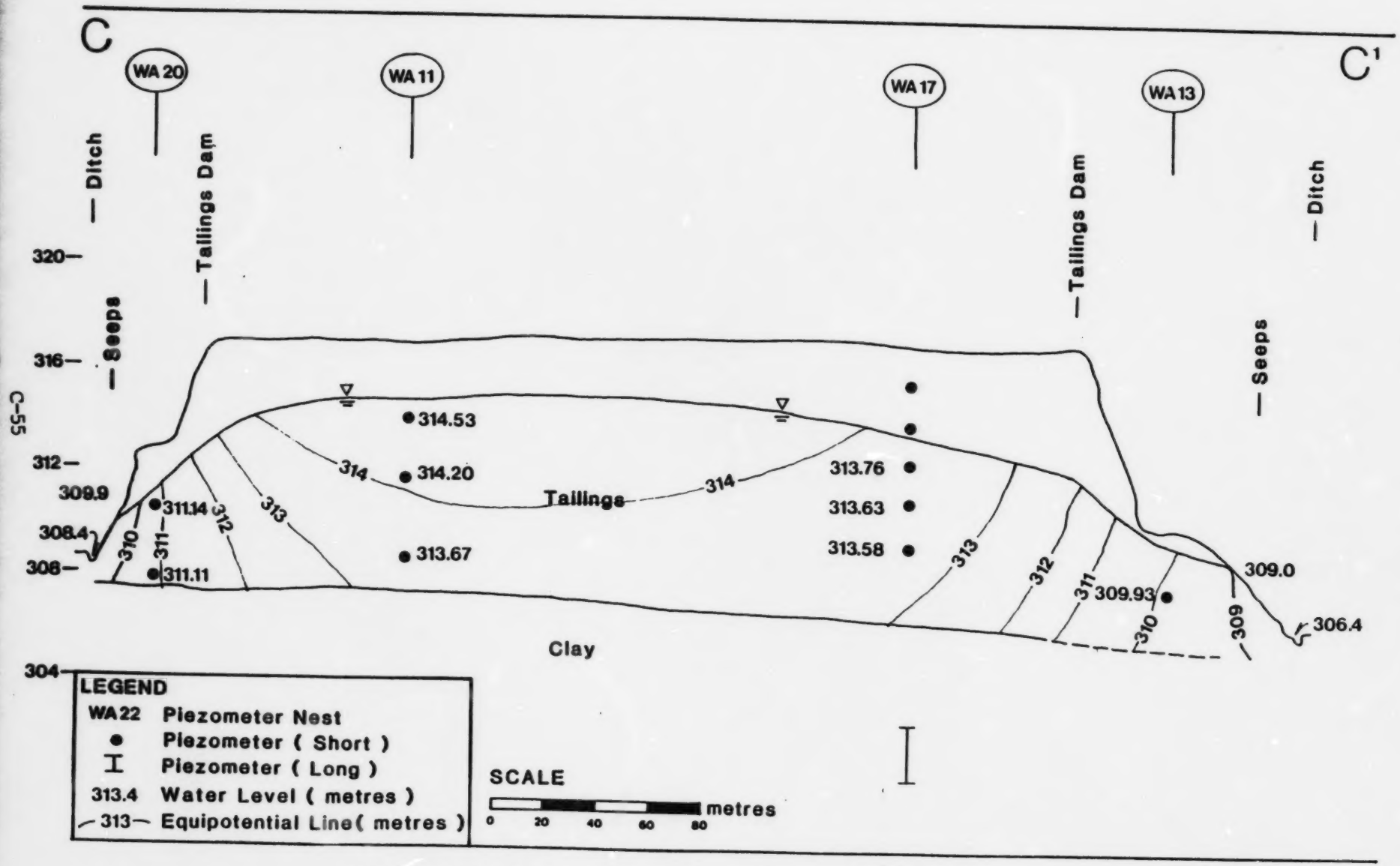


FIGURE 3C WATER LEVEL DISTRIBUTION

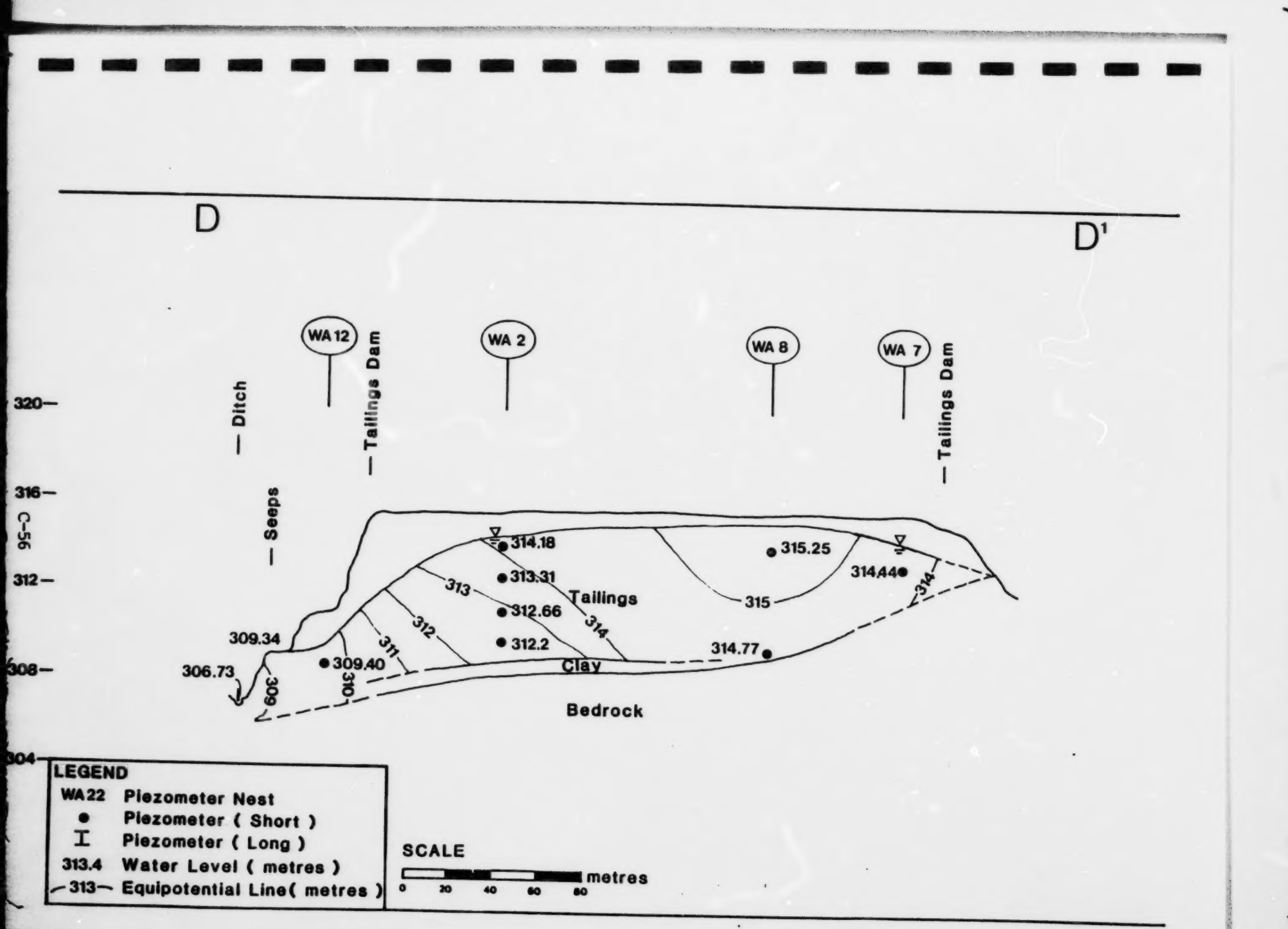


FIGURE 21 WATER LEVEL DISTRIBUTION

From the water level profiles obtained to date there appears to be a wide variation in the vertical hydraulic gradients across the site. Gradients range from almost non-existent at WA22 to greater than 0.5 at WA2.

Generally, the vertical gradients indicate a downward component of flow across the tailings site. Piezometers located along the tailings dam show only a very small downward vertical gradient and in fact at WA19 although the vertical gradient is almost non-existent it is an upward gradient. Looking at Figures 19 and 209, a comparison of water levels in the piezometer nests along the tailings dam, water levels along the drainage ditches, and the elevation of the seepage face, indicates that an upward gradient or discharge exists between the tailings dam and the drainage ditch near the base of the tailings dam. In the south portion of the tailings area where the underlying clay is very thick it is expected that the porewater within the tailings would discharge into the ditches around the base of the tailings, although some porewater flow may occur under the ditch at the south end because of the depth of tailings extends below the ditch.

In the northeast portion of the site (WA5, WA10) the vertical gradients are relatively small compared to the gradients in the nests of wells surrounding (i.e. WA2, WA8, WA9, WA1) this area. This appears to be an area where the bedrock is shallow and little clay is present between

the bedrock and tailings. These vertical gradients do not show a significant component of downward movement of groundwater relative to the area surrounding it indicating little hydraulic connection to the underlying bedrock (Figure 21).

In the northwestern portion of the site (i.e. WA2) there is a very strong downward vertical gradient (greater than 0.5) indicating an underlying zone of higher hydraulic conductivity. Figure 21 shows the variation in water levels across the northern portion of the site. even if this area is hydraulically connected to the bedrock the hydaulic conductivity is low and the volume of porewater migration will be minimal compared to the water moving through the dam (see Section 3.5).

General Groundwater Flow

Based on the water table configuration and vertical water level profiles it appears that porewater within the tailings is generally moving outward from the centre of the tailings through the coarse-grained tailings dam and discharging into the surrounding drainage ditch either directly or along a line of seeps on the tailings dam. It should be noted that the elevation and flow from these seeps increase very quickly after a rainfall event.

The underlying clay would act as a barrier to downward movement of porewater from the tailings in the south portion of the site. In the

north portion, it appears that there is little hydraulic connection with the shallow bedrock in the northeast but there may be a good hydraulic connection with the bedrock below, or at least a high hydraulic conductivity zone below the tailings.

3.4 Hydraulic Conductivity Results

Hydraulic conductivities of tailings solids were determined at 39 piezometer locations. Table 1 shows the results of the testing.

Hydraulic conductivities ranged from 9×10^{-7} cm/sec to 1.4×10^{-3} cm/sec. Low hydraulic conductivities (1.0×10^{-6} - 9.0×10^{-7} cm/sec) were generally found in the north end of the tailings where the finest grained tailings were deposited. The highest hydraulic conductivities (1.4×10^{-3} - 1.2×10^{-4} cm/sec) were generally found in the south end of the tailings. Several high hydraulic conductivities were found along the tailings dam, however in some cases water levels recovered too quickly to obtain accurate values, indicating that the hydraulic conductivity of the tailings dam is generally greater than the tailings. Figure 22 through 25 show the hydraulic conductivity distribution along cross-sections A-A' through D-D' respectively.

A general trend of decreasing hydraulic conductivity with depth was evident at a number of piezometer nests, with the exception that many of the hydraulic conductivities in the shallow porewater zone were lower than values obtained below this zone. Cross-section A-A' (figure 22) shows a general increase in hydraulic conductivity from

Piezometer	Depth (m)	Hydraulic Conductivity (cm/sec)
1-1	7.9	1.4×10^{-6}
1-2	2.4	7.1×10^{-5}
2-1	5.9	1.3×10^{-6}
2-2	1.5	2.0×10^{-6}
2-3	4.5	3.6×10^{-5}
2-4	3.0	2.9×10^{-6}
3-1	5.0	6.4×10^{-6}
4-2	1.4	2.2×10^{-3}
5-1	4.9	5.6×10^{-6}
5-2	1.7	4.4×10^{-6}
6-1	2.1	2.8×10^{-6}
7-1	2.4	2.0×10^{-5}
8-1	5.9	9.0×10^{-7}
8-2	1.5	2.2×10^{-6}
9-1	6.6	1.1×10^{-6}
9-2	1.5	5.6×10^{-6}
9-3	5.0	3.0×10^{-6}
9-5	2.5	1.4×10^{-5}

Table 1: Hydraulic Conductivity Results

Piezometer	Depth (m)	Hydraulic Conductivity (cm/sec)
10-1	7.3	6.5×10^{-6}
11-1	8.2	1.2×10^{-5}
11-2	5.2	1.2×10^{-5}
13-1	2.4	5.8×10^{-4}
14-1	1.5	2.1×10^{-4}
15-1	6.4	4.7×10^{-5}
17-1	7.6	1.8×10^{-4}
17-2	6.0	2.2×10^{-4}
17-3	4.5	2.9×10^{-4}
18-2	11.0	2.0×10^{-5}
18-3	9.5	3.0×10^{-5}
18-4	7.9	2.4×10^{-5}
20-1	4.9	2.1×10^{-4}
21-1	4.9	2.5×10^{-4}
22-1	11.0	1.0×10^{-4}
22-2	9.5	1.3×10^{-3}
22-3	7.9	1.4×10^{-3}
22-4	6.4	1.9×10^{-4}

Table 1: Hydraulic Conductivity ResultsB

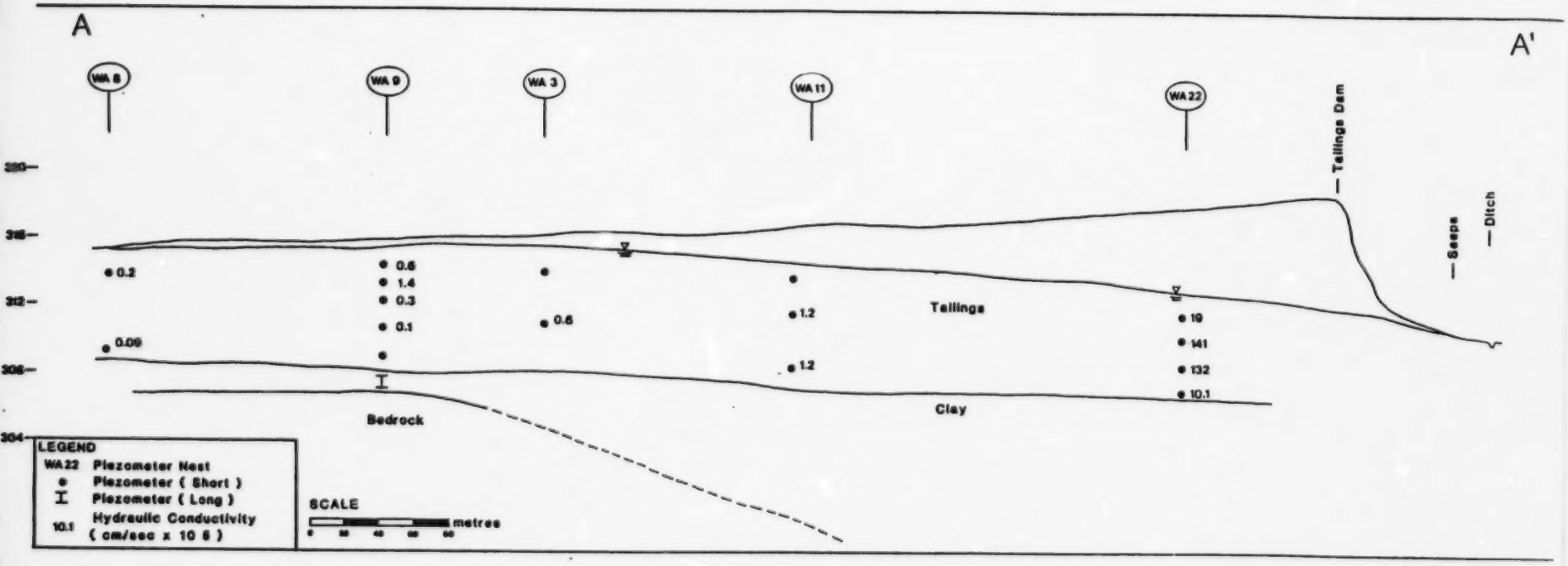
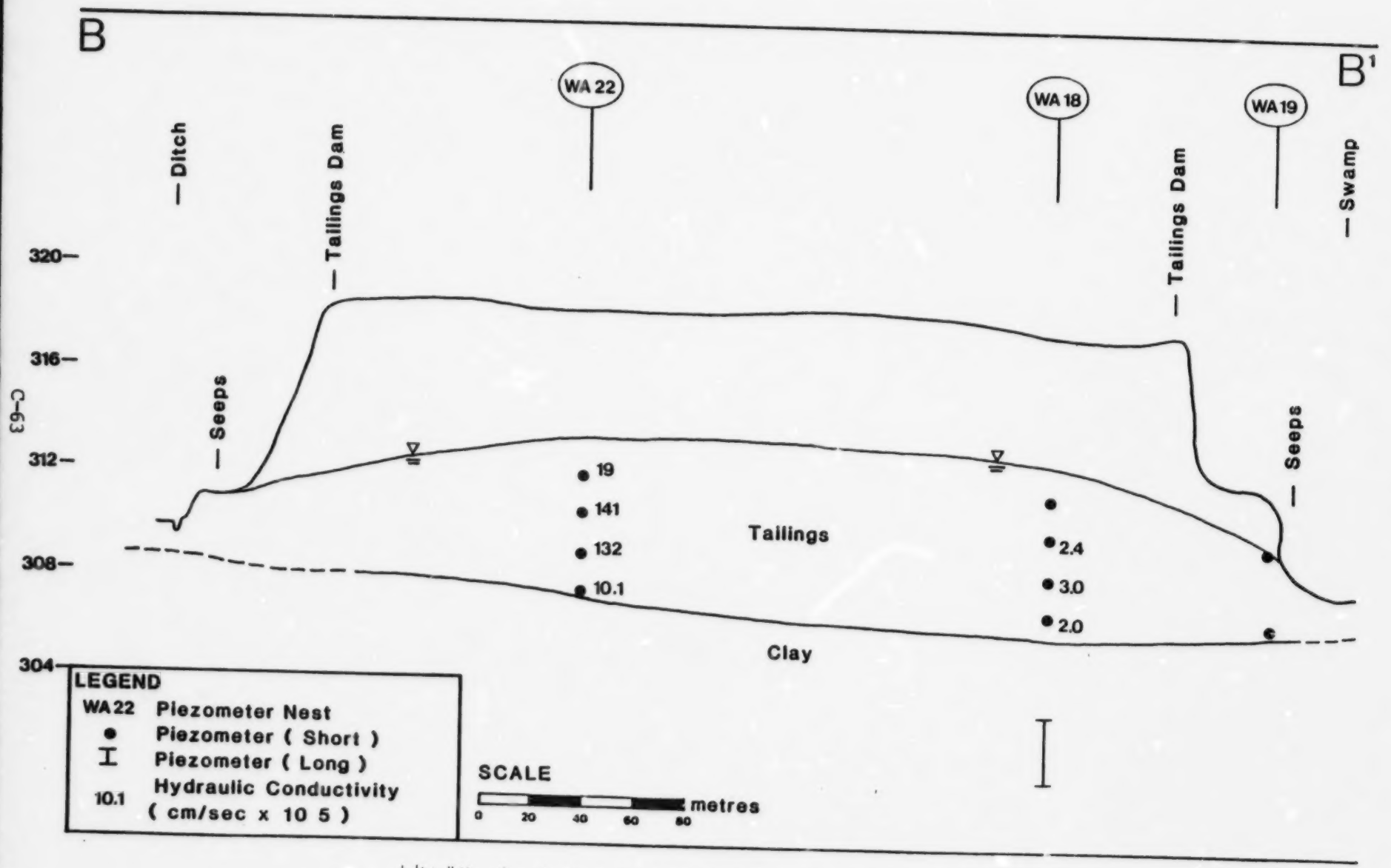
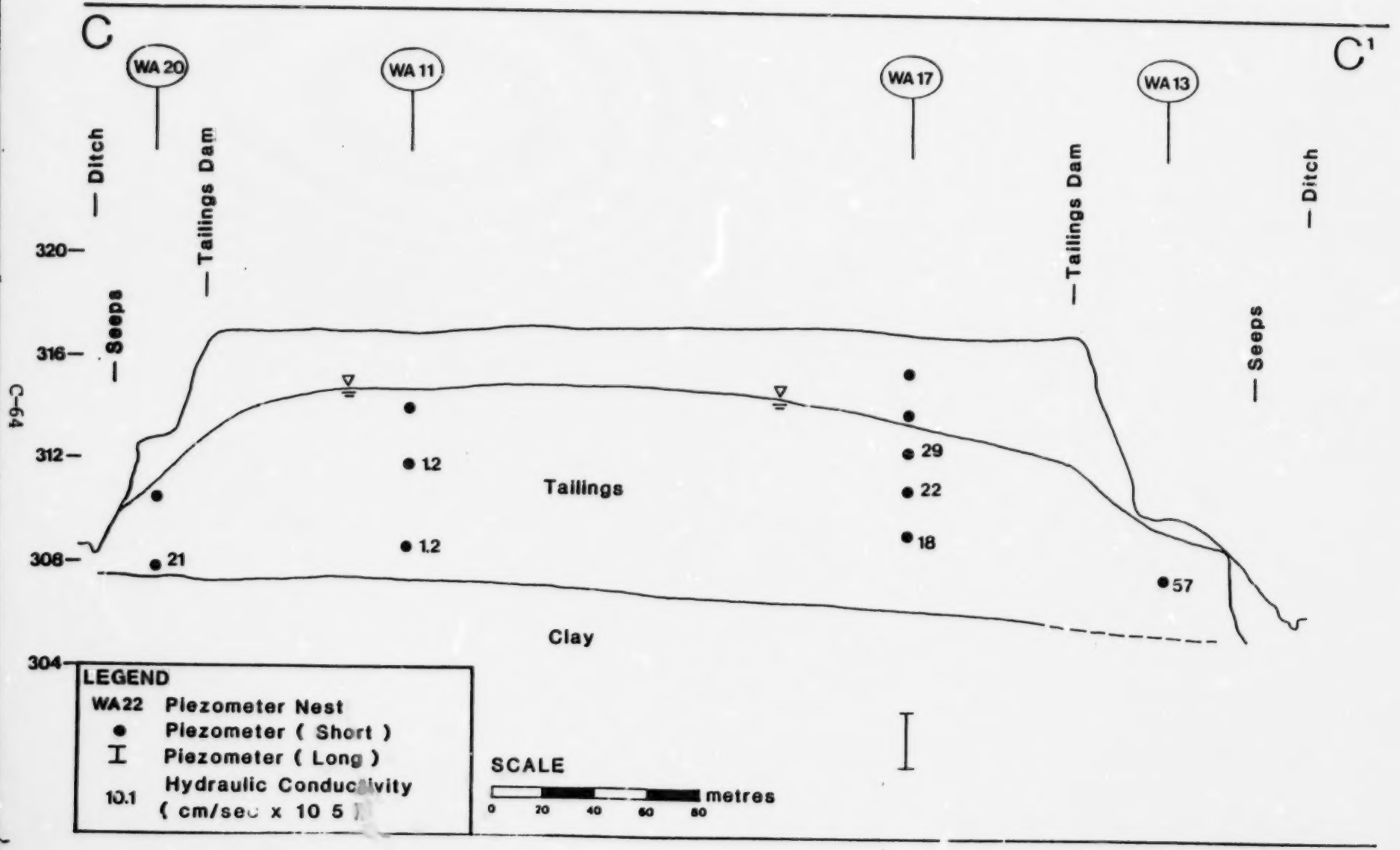


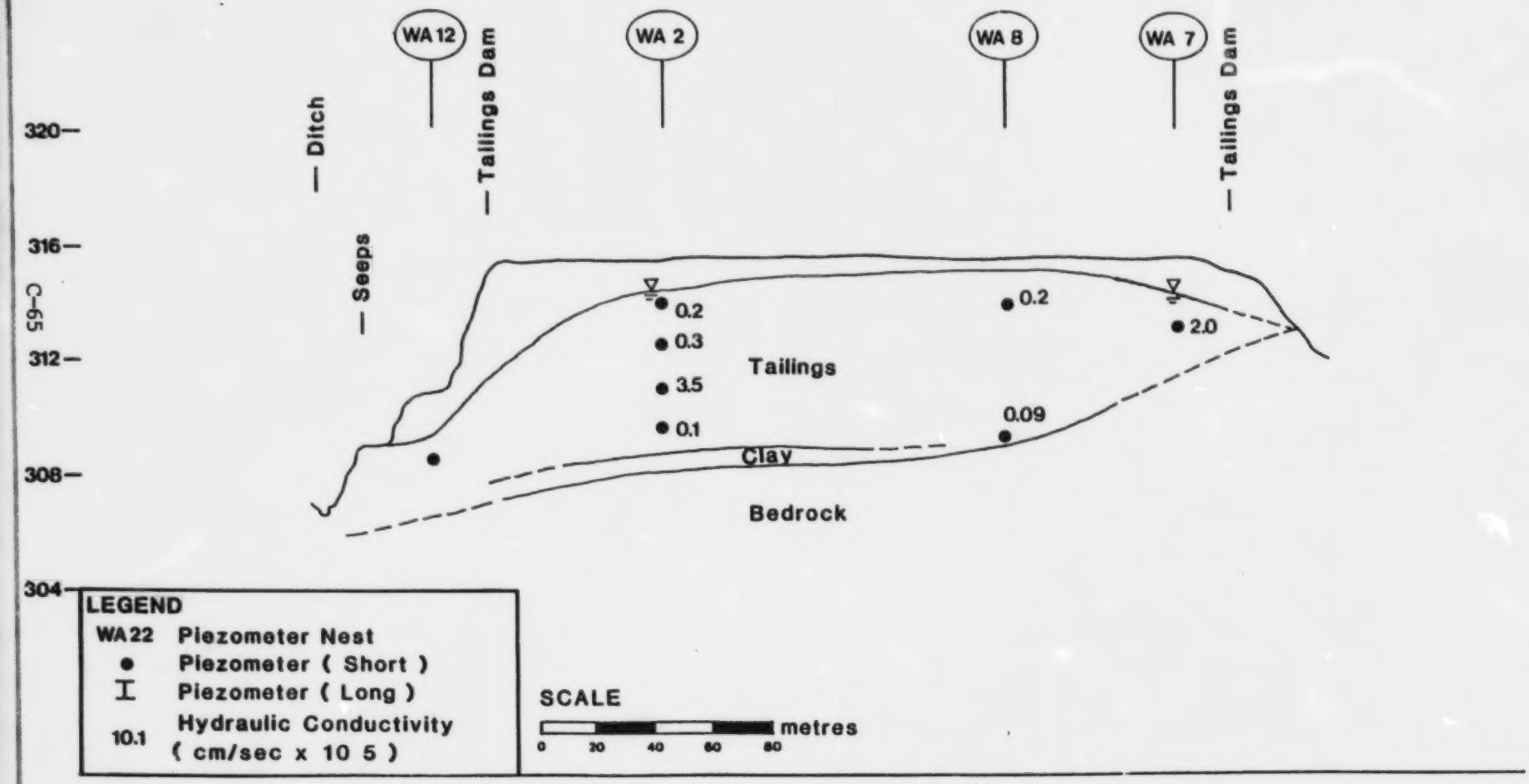
FIGURE 22 HYDRAULIC CONDUCTIVITY - CROSS-SECTION A-A'


B
B1
WA 22
WA 18
WA 19
Ditch
Tailings Dam
Tailings Dam
Swamp
Seeps
Seeps
320
316
312
308
304
19
141
132
10.1
Tailings
2.4
3.0
2.0
Clay
LEGEND
WA22 Piezometer Nest
Piezometer (Short)
Piezometer (Long)
10.1 Hydraulic Conductivity (cm/sec x 10 5)
SCALE
metres
0 20 40 60 80

C-63


C
C'
WA 20
WA 11
WA 17
WA 13
Ditch
Tailings Dam
Seeps
Tailings Dam
Seeps
Ditch
320
316
312
308
304
Tailings
Clay
12
1.2
29
22
18
21
57
LEGEND
WA22 Piezometer Nest
Piezometer (Short)
Piezometer (Long)
10.1 Hydraulic Conductivity (cm/sec x 10 5)
SCALE
0 20 40 60 80 metres

C-64


D
D'
WA 12
WA 2
WA 8
WA 7
Ditch
Tailings Dam
Tailings Dam
Seeps
320
316
312
308
304
C-95
0.2
0.3
3.5
0.1
0.2
2.0
0.09
Tailings
Clay
Bedrock
LEGEND
WA22 Piezometer Nest
Piezometer (Short)
Piezometer (Long)
10.1 Hydraulic Conductivity (cm/sec x 10 5)
SCALE
metres
0
20
40
60
80

north to south by about three orders of magnitude. The two detailed piezometer nests (WA9 and WA22) along this section, show a slight decrease in hydraulic conductivity with depth, except for the shallowest piezometer, by slightly greater than an order of magnitude.

It should be noted that WA22, at the south end of Cross-section A-A' is located near what was a main discharge spigot and the tailings at this location have the highest hydraulic conductivites found on site.

3.5 Preliminary Groundwater Flux and Velocity Estimates

Based on water level data discussed in Section 3.3 and hydraulic conductivity data presented in the previous section, preliminary values of groundwater fluxes and velocities are presented here to serve as estimates to further investigate the groundwater regime.

Groundwater Flux

In order to calculate the quantity of groundwater moving out of the tailings several assumptions and generalizations must be made. The following assumptions are made. Groundwater leaving the tailings exits through the tailings dam and discharges into the drainage ditch at the base of the dam, either directly or from seeps along the perimeter of the dam. This is probably a reasonable assumption considering the underlying clay across much of the site will prevent movement of groundwater downward, however there may be some porewater migrating into the bedrock in the northwest portion of the

site and also migrating under the ditch at the south end of the site. It is assumed that the area of discharge is the length of the tailings dam surrounding the site (approximately 1500 m) and is about 2 m high based on the location of drainage ditches and seeps along the perimeter of the dam.

Using the Darcy equation:

$$q = K\,I\,A$$

where q is the rate of groundwater flow (L^3/T), K is the hydraulic conductivity (L/T), I is the hydraulic gradient (L/L) and A is the cross-sectional area (L^2) through which the water is moving, an estimate of flow can be made.

The hydraulic conductivity and gradients used are values generalized across the tailings dam which will dictate the rate of groundwater discharge along the base of the dam. A hydraulic conductivity of 1.5×10^{-3} cm/sec was assumed for the tailings dam as some values were higher and some lower than this value. This value also corresponds to the highest hydraulic conductivity value found in the coarse fraction of tailings. The dam was constructed by spigotting in the summer and end spilling in the winter and is likely to be made up of coarse fraction material. Results of drilling also indicate this. The hydraulic gradient across the tailings dam was taken to be about 0.03.

Using the Darcy equation and the above values the resulting flux is:

$$q = 1.5 \times 10^{-5} \text{ m}^3/\text{sec} \times 0.03 \times 1500 \text{ m} \times 2 \text{ m}$$

$$= 1.35 \times 10^{-3} \text{ m}^3/\text{sec}$$

This is equivalent to 80 Lpm discharging through the tailings dam into the perimeter ditches. Because of the variability in the parameters used for this calculation the discharge could range from 8 to 800 Lpm.

Previous work done by the Centre de Recherche Noranda indicates that stream flow measurements taken in the Summer of 1984 from the surface ditches around the main tailings show flow rates ranging from 70 Lpm, to 146 Lpm well within the estimated range. These values also include a small contribution from an area other than the main tailings so they are probably slightly lower than presented.

Utilizing meteorological data from the same study by Centre de Recherche Noranda it was estimated that about 30 cm of precipitation would be available for infiltration after evapo-transpiration. The main tailings area is approximately 40 ha in size so the total water available for infiltration is on the order of 1.2×10^5 m^3/year. This rough approximation is equivalent to an average discharge of 225 Lpm. This value may in fact be less when considering that during periods of increased precipitation and spring run-off there is a considerable quantity of surface run-off out of the north central area of the site through a stream channel cut into the north dam area.

The above calculations are within reasonable agreement, considering the uncertainties involved with the parameters used. Each method could be refined with more data collection however there will always be uncertainly involved with any of the calculations.

Groundwater Velocity

The velocity of porewater movement through the tailings is dependent on the hydraulic conductivity of the material and the hydraulic gradient. Because of the spatial variability in hydraulic conductivity and the spatial and time variability in hydraulic gradients only a range of velocity estimates is presented here.

Porewater velocities are determined using the equation:

$$V = \frac{K I}{n}$$

Where V is the average linear porewater velocity (L/T), K is the hydraulic conductivity (L/T), I is the hydraulic gradient (L/L) and n is the porosity of the material. Horizontal velocities are determined using the horizontal hydraulic conductivity (K_h) and the horizontal hydraulic gradient. Vertical velocities of porewater are determined using vertical hydraulic conductivities (K_v) and gradients. Hydraulic conductivities collected to date represent horizontal values however the length of the piezometer tip is sufficiently small to give a

reasonable value of vertical hydraulic conductivity. It should be noted that porewater velocities in the vertical direction are dependent primarily on the lowest hydraulic conductivity layer through which the water is moving. An average porosity of 0.35 was used in all calculations.

Horizontal porewater velocities within the tailings range from a maximum of 5 m/year in the south portion of the site to a minimum of 0.4 cm/year in the northern portion of the site. The maximum values are in the southern area of the tailings are in the vicinity of WA22, where the hydraulic conductivity is the highest within the tailings. More representative velocities across the southern area are .3 - .5 m/year. In the northern portion of the site the minimum velocities of 0.4 cm/year are based on a hydraulic conductivity of 2×10^{-6} cm/sec and gradient of 2.0×10^{-3} which is a reasonable representation of average values across this area of the site.

Vertical porewater velocities vary considerably across the site. In the southern portion of the site the area with the highest hydraulic conductivity (WA22) has the lowest vertical gradient, and velocities would be about 1.3 m/year. However as mentioned previously, the vertical velocities are affected most by the low hydraulic conductivity zones. For example at WA22 the shallow and deep zones (WA22-1, WA 22-4) have hydraulic conductivities about an order of magnitude lower than the middle zone which would result in velocities on the order of 13 cm/year through these zones.

The highest vertical velocities to date are found at WA17. Using a hydraulic conductivity of 2.0×10^{-4} cm/sec and a gradient of .06 groundwater velocities are on the order of 10 m/year. It should be noted however that numerous thin layers of tailings slimes were encountered both above and below the water table, which would decrease the downward movement of water by a substantial amount. The lowest vertical velocities are found in the northern portion of the site and are on the order of 0.07 m/year.

porewater velocities across the tailings dam are on the order of 35 m/year in the horizontal direction using a hydraulic conductivity of 1×10^{-3} cm/sec and a gradient of 0.04.

3.6 Electrical Conductance and pH

Electrical conductance and pH measurements were taken at all piezometers which yielded sufficient water and at selected surface water locations. Table 2 presents the results of electrical conductance (Ec) and pH measurements taken on porewater in September and October, 1985. Table 3 presents the results at surface water locations. Figures 26 through 29 show the variation in Ec and pH across cross-sections A-A' through D-D'. Figure 30 shows the location and Ec and pH results for surface water sampling points around the tailings site.

Results indicate that the pH below the water table across the

Piezometer	Depth (m)	pH	Electrical Conductance (uS)
1-1	7.9	7.55	3000
1-2	2.4	7.95	5120
2-1	5.9	7.35	3100
2-2	1.5	7.80	6060
2-3	4.5	6.55	7200
2-4	3.0	7.45	6100
3-1	5.0	7.30	6870
3-2	2.0	7.35	2520
4-1	2.7	6.50	1975
4-2	1.4	4.75	7890
5-1	4.9	6.25	2750
5-2	1.7	6.45	11930
6-1	2.1	6.80	5000
7-1	2.4	6.55	6440
8-1	5.9	6.60	1440
8-2	1.5	7.50	6650
9-1	6.6	7.05	1920
9-2	1.5	7.05	3790
9-3	5.0	7.20	5940
9-4	3.5	7.40	7900
9-5	2.5	7.50	4950
9-6	7.9	6.85	3600
10-1	7.3	7.45	1830
10-2	1.5	8.15	2400
11-1	8.2	6.60	2960
11-2	5.2	7.05	6350
11-3	3.0	5.60	6200
12-1	2.4	6.40	5840
13-1	2.4	6.00	5980
14-1	1.5	5.30	8210

Table 2: Electrical Conductance and pH - Groundwater

Piezometer	Depth (m)	pH	Electrical Conductance (uS)
15-1	6.4	7.25	5090
15-2	3.7	-	-
16-1	6.1	-	-
17-1	7.6	7.00	5740
17-2	6.0	6.90	7420
17-3	4.5	7.20	7620
17-4	3.0	-	-
17-5	1.5	-	-
17-6	14.6	-	-
18-1	14.9	-	-
18-2	11.0	7.05	4230
18-3	9.5	7.25	5940
18-4	7.9	7.20	6810
18-5	6.4	6.65	7160
19-1	5.8	7.00	3200
19-2	2.4	6.10	10230
20-1	4.9	6.55	1850
20-2	2.4	6.05	9000
21-1	4.9	6.90	5150
21-2	2.9	6.95	7100
22-1	11.0	7.15	3670
22-2	9.5	7.46	4000
22-3	7.9	7.15	7500
22-4	6.4	7.05	7640

Table 2: Electrical Conductance and pH - Groundwater

Location	pH	Electrical Conductance (us)	Comments
SW 1	7.60	1320	exit at the north dam
SW 2	3.25	5060	wine-coloured pools below dam
SW 3	4.00	1000	tributary before main ditch
SW 4	3.50	7800	main ditch upstream
SW 5	3.60	6500	main ditch downstream
SW 6	3.25	5170	drainage ditch below dam
SW 7	7.15	315	drainage ditch west of road
SW 8	7.55	150	pond west of road
SW 9	3.45	9500	tailings drainage ditch
SW 10	3.45	12500	seeps above drainage ditch
SW 11	3.90	2800	drainage ditch west of berm
SW 12	3.50	4600	drainage ditch from tailings
SW 13	6.80	280	ditch east of railroad bed
SW 14	6.00	1300	ditch east of berm
SW 15	5.25	1800	water from discharge line
SW 16	4.10	850	drainage ditch
	3.85	11500	seeps below WA 12
	3.80	4890	seeps below WA 13
	3.30	10720	seeps below WA 14
	3.15	11600	seeps below WA 20
	3.10	7430	ditch below WA 20

Table 3: Electrical Conductance and pH - Surface Water
(see Figure 30)

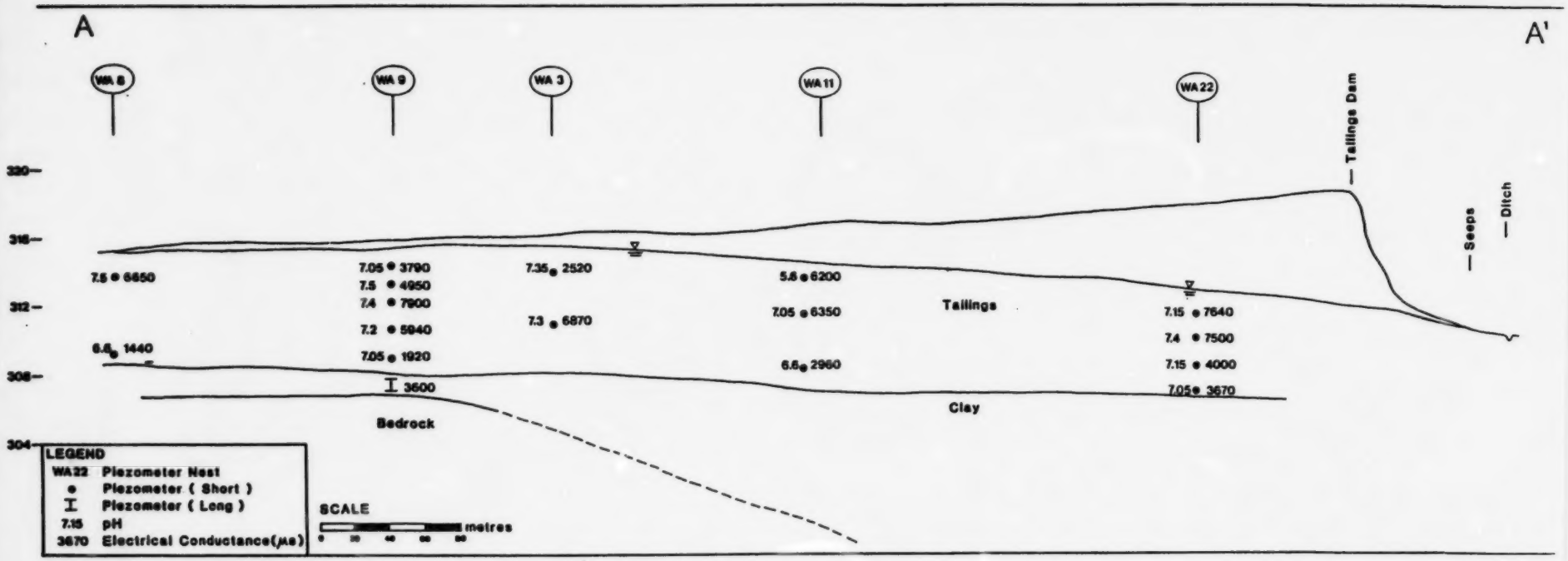


FIGURE 26 ELECTRICAL CONDUCTANCE AND PH A-A'

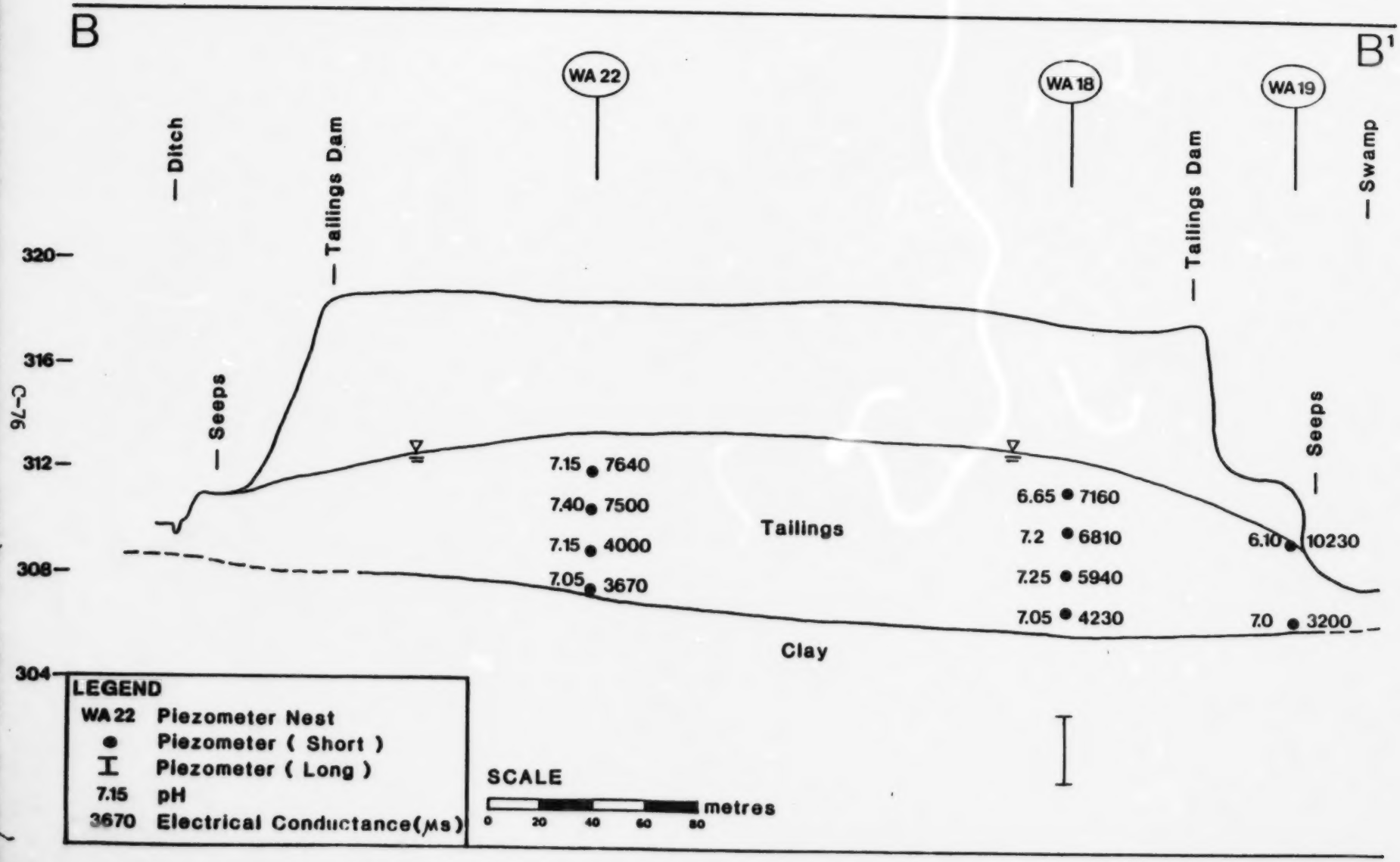
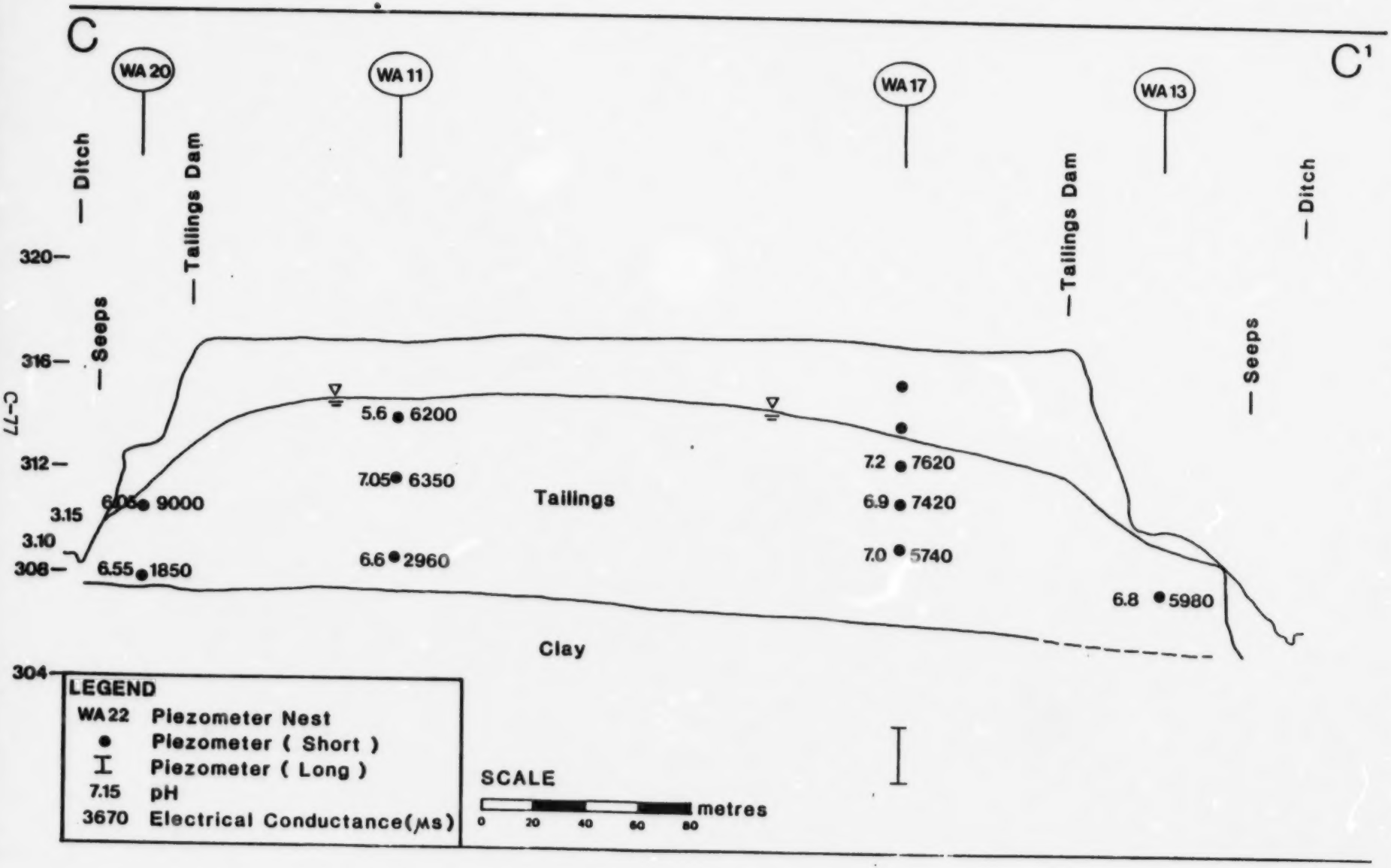
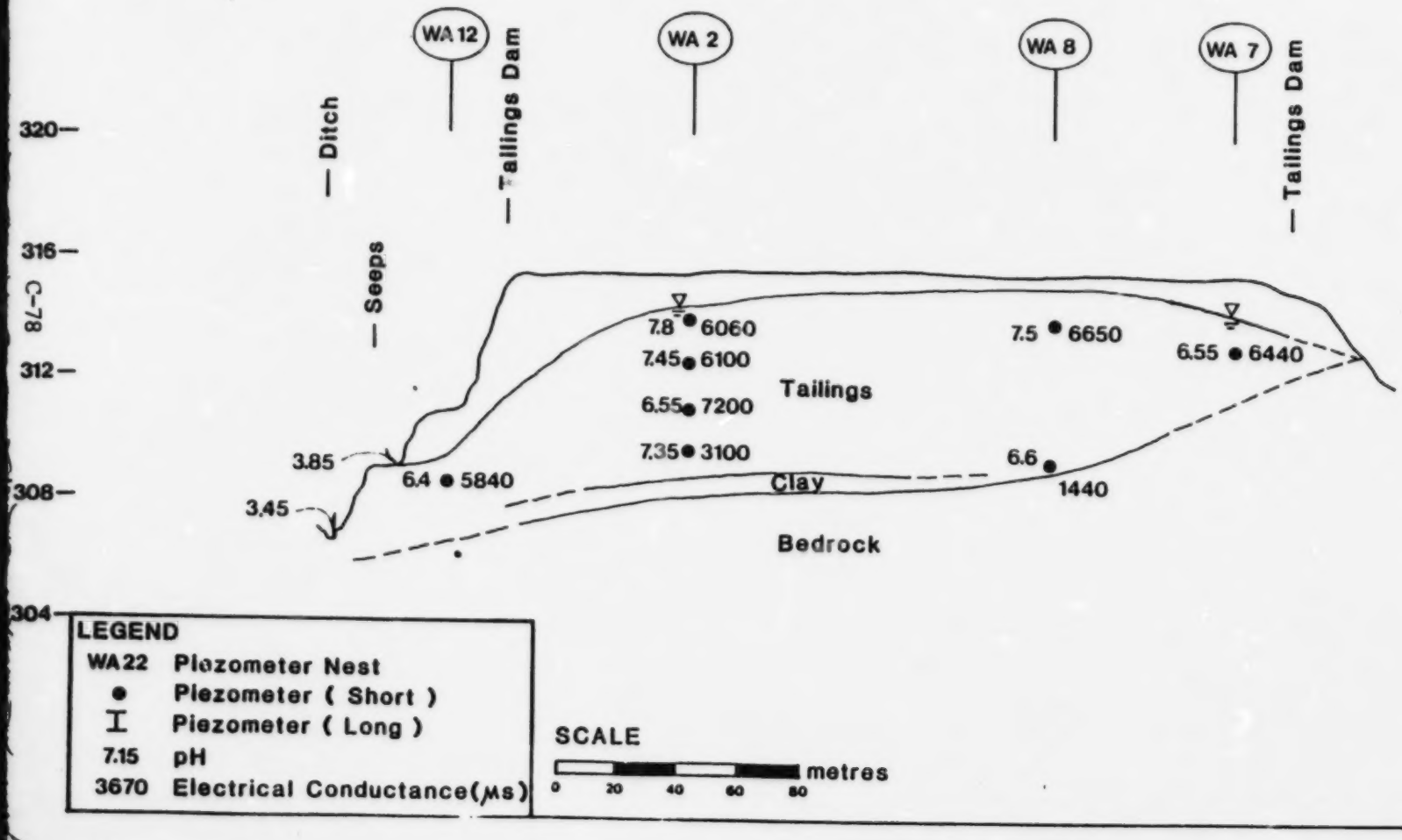
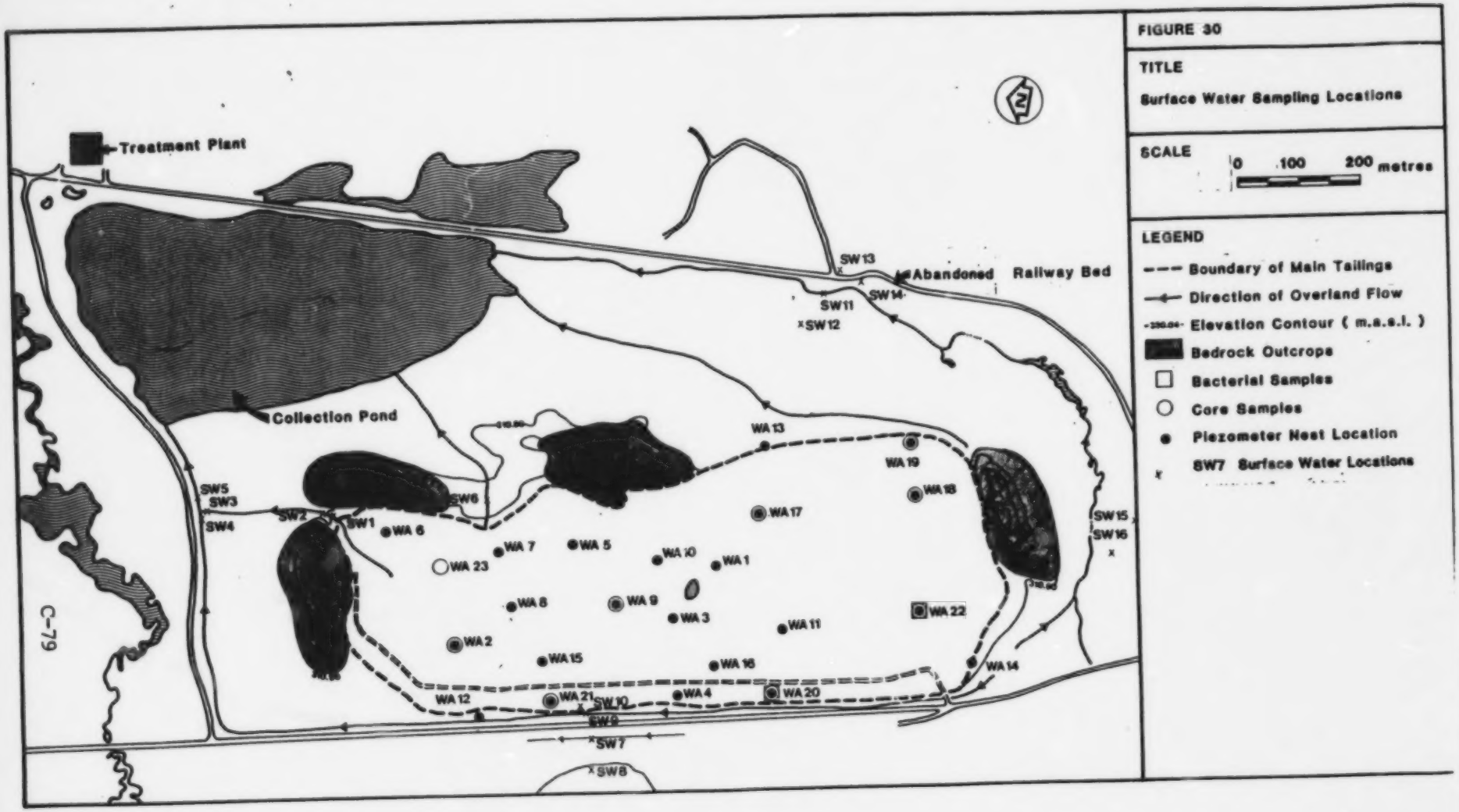


FIGURE 27 ELECTRICAL CONDUCTANCE


C
C'
WA 20
WA 11
WA 17
WA 13
Ditch
Tailings Dam
Tailings Dam
Ditch
Seeps
Seeps
320
316
312
308
304
C-77
5.6 6200
7.05 6350
6.6 2960
7.2 7620
6.9 7420
7.0 5740
6.8 5980
6.55 1850
3.15
3.10
Tailings
Clay
LEGEND
WA 22 Piezometer Nest
Piezometer (Short)
Piezometer (Long)
7.15 pH
3670 Electrical Conductance(μs)
SCALE
0 20 40 60 80 metres


D
D'
WA 12
WA 2
WA 8
WA 7
Ditch
Tailings Dam
Seeps
Tailings Dam
320
316
312
308
304
C-78
7.8 ● 6060
7.45 ● 6100
6.55 ● 7200
7.35 ● 3100
7.5 ● 6650
6.55 ● 6440
6.6 ● 1440
6.4 ● 5840
3.85
3.45
Tailings
Clay
Bedrock
LEGEND
WA22 Piezometer Nest
● Piezometer (Short)
I Piezometer (Long)
7.15 pH
3670 Electrical Conductance(μs)
SCALE
metres
0 20 40 60 80


Treatment Plant
Collection Pond
Abandoned Railway Bed
SW13
SW14
SW11
SW12
SW5
SW3
SW4
SW2
SW1
SW6
WA 6
WA 7
WA 5
WA 23
WA 10
WA 1
WA 8
WA 9
WA 3
WA 2
WA 15
WA 16
WA 12
WA 21
SW10
WA 4
WA 20
SW9
SW7
SW8
WA 13
WA 19
WA 18
WA 17
SW15
SW16
WA 22
WA 11
WA 14
C-79
FIGURE 30
TITLE
Surface Water Sampling Locations
SCALE
0 100 200 metres
LEGEND
Boundary of Main Tailings
Direction of Overland Flow
Elevation Contour (m.a.s.l.)
Bedrock Outcrops
Bacterial Samples
Core Samples
Piezometer Nest Location
SW7 Surface Water Locations

site was generally greater than 6.0. Water in several piezometers just below the water table on the dam bench (WA 14, WA 4-2) had a pH between 5 and 6. The only piezometer on the main tailings which had a pH below 6.0 was WA 11-3 in the shallow water table zone.

All of the surface water locations (Figure 30) around the base of the tailings had a pH of less than 4.0 except the main runoff from the north end of the site (SW 1) which had a pH of 7.6. This high pH surface water moves over the top of the tailings in an area which has had 0.3 m of clay cover placed on top. Seeps beside the stream had a pH of less than 4.0.

Electrical conductance of water within the tailings varied from about 1,800 uS to 12,000 uS. Surface water around the perimeter of the dam had Ec's ranging from 4,800 uS to 11,600 uS. Surface water locations away from runoff from the tailings (i.e. west of the site) had Ec's ranging from 150 to 315 us.

Figures 26 through 29 indicate that there is little evidence of vertical profile trends in pH below the water table, other than the slightly lower pH in the porewater zone just below the water table. Electrical conductance generally shows a decrease with depth at most locations. This decrease is generally a factor of two to three. The main exceptions to this general trend are at WA 9 and WA 2 which show the most elevated values of Ec in the middle of the tailings. These locations also have the strongest downward vertical gradients found

across the site. Electrical conductance of seepage waters around the perimeter of the dam generally show more elevated values than groundwater in the tailings adjacent to these seeps. Because the pH is significantly lower in these seeps the higher electrical conductance is likely due to dissolution and mobilization of more metals.

Electrical conductance and pH values outside the main tailings area (SW 7, SW 8, SW 13) indicate no evidence of waters from the tailings area leaving the main drainage ditches and this is supported by the water level data precluding flow in those directions.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Results of the hydrogeological investigations to date at the Waite-Amulet tailings indicate the tailings area to be reasonably contained and is contributing little water to the regional groundwater system. The majority of water infiltrating into the tailings discharges into the drainage ditches around the perimeter of the tailings dam, either directly or by surface seeps at the base of the dam. This contaminated water is collected in a reservoir northeast of the tailings area, treated and discharged to Duprat Creek. The southern portion of the site is underlain by a thick (greater than 10 m) impermeable varved clay. In the northern portion of the site the bedrock is nearer ground surface and in some areas there is only a thin veneer of a clayey silt to silt till between the tailings and bedrock. Strong downward gradients in these areas indicate a hydraulic connection or at least a high hydraulic conductivity zone below the tailings.

Water level monitoring within the tailings indicates a shallow water table near the tailings surface in the north, and a deeper water table (5-6 m) in the southern portion of the site. The tailings in the north are generally fine-grained and have a low-hydraulic conductivity (2×10^{-6} cm/sec). The grain size and hydraulic conductivity increase to the south with the maximum hydraulic conductivity being 1.3×10^{-3} cm/sec. It should be noted however, that numerous fine slime layers

were encountered within the tailings, during drilling in the south of the site. The layers encountered above the water table were saturated while the coarse-grained fraction was only slightly moist. These layers may seriously impede the downward vertical movement of water to the water table.

The water table indicates a high in the centre of the site with a radial movement of water outwards towards the tailings dams. The northeast portion of the site, where bedrock abuts the tailings, there is little water table slope, and the water table is high, indicating little movement of water into the adjacent bedrock. Vertical gradients are also very low throughout this area indicating little movement of water into the underlying bedrock. Large vertical gradients exist in the northwest portion of the site indicating a higher hydraulic conductivity zone below the tailings.

The water table slope is very steep, adjacent to and through the tailings dam. The tailing dams is constructed of coarse-grained tailings and as a result do not impede water movement. A seepage face exists around the perimeter of the dam throughout the entire site. It should be noted that during periods of rainfall the quantity of water exiting this seepage face increases substantially and the top of the seepage face generally migrates up the slope of the dam.

Estimates of porewater discharge out of the seepage face compared reasonably well with estimates of infiltration and volume of stream

flow around the perimeter of the site. Volumes were on the order of 70 Lpm to 225 Lpm.

Estimates of porewater velocities ranged from .3 cm/year to 11 m/year depending on the spatial variation in hydraulic conductivity and hydraulic gradient. Velocities appear to be greater in the horizontal direction in the southern portion of the site and greater in the vertical direction in parts of the northern portion of the site.

Values of pH obtained across the site indicate little presence of acid water below the water table with pH values generally in the range of 6.0 to 7.5. Some slightly lower pH values were found at a few shallow piezometers located just below the water table. Waters in drainage ditches and seepage areas around the perimeter of the dam had pH values less than 4.0. Work done by the University of Waterloo indicates pH values of between 3 and 4 in the unsaturated zone. The work is being performed by Mr. David Blowes, a PhD student in Earth Sciences, through scholarship funding by Noranda. Groundwater samples showed little change in pH when exposed to the atmosphere indicating a relative chemical stabilization of this water. These results would indicate that much of the discharge water is from the unsaturated zone or very shallow water table or there is some sort of geochemical affect as the water moves through the tailings dam and discharges to the surface environment.

Electrical conductance (Ec) values ranged from 1,900 uS to 10,980 uS within the tailings and showed a general decrease with depth at most locations, except that the shallow groundwater zone often had lower values than the zones below.

Geophysical investigations performed on the site indicate the bedrock topography, especially in the north portion of the site to vary considerably more than anticipated. Seismic investigations correlated reasonably well with the borehole data, however no significant variation in seismic velocity was noted between the fine-grained tailings and shallow water-table in the north portion of the site and the course-grained tailings and deeper water table in the south portion of the site.

Bulk electrical conductivity variations, from geophysical methods, within the tailings have been outlined, however because of the high percentage and variability of metal content in the tailings solids, it is difficult to determine variations in the electrical conductance of porewater across the site. Results of conductivity studies indicate contamination to be highest near the surface and confined to the tailings material only. A correlation may be made when results of metal analyses of core samples become available where it might be more useful.

Recommendations

Results of the preliminary hydrogeological investigation indicate several locations where further data would be useful and indicate the need for certain types of studies not yet conducted. Although the hydrogeology of the site is reasonably well-defined from this phase of study there are specific locations where more data would better define the hydrogeologic setting. It is recommended that the following studies would enhance the complete hydrogeologic data base of the study area:

1) Better topographic and hydrogeologic definition of the bedrock underlying the northern portion of the site.

This would involve doing follow-up geophysical work, and drilling into bedrock and installing piezometers into the bedrock. Because of the highly variable bedrock relief more detailed seismic coverage in this area would better define the thicknesses of the geologic units and refine the drilling locations to optimize cost. An alternative to seismic refraction would be seismic reflection which enables an enhancement of cross-sectional "pictures" of the site.

Drilling into bedrock and installing piezometers will determine the degree of hydraulic connection between the bedrock and

overlying tailings in the north portion of the site. Large vertical downward gradients in the tailings indicate a high hydraulic conductivity zone below the tailings and should be investigated.

2) Examine the groundwater flow system within the tailings at the south end of the site.

The tailings at south of the main tailings dam appear to be at least 3-4m. below the elevation of the surface drainage ditch. It is not known at present where water moving through these tailings would likely discharge and should be investigated with a series of piezometers installed to look at the hydraulic gradients.

3) Refine the velocity and flux calculations of water moving through the tailings dam.

A more detailed examination of the hydraulic gradients across the tailings dam and the hydraulic conductivity of the material in the tailings dam will allow for a much better determination of rates and volumes of water leaving the tailings dam and entering the surface runoff ditches.

Results to date indicate there is need for detailed investigations of the unsaturated zone and water table zone, as well as the contact area where the groundwater enters the surface regime along the tailings

dam. Preliminary studies by Mr. David Blowes at the University of Waterloo shows low pH water (3-4) in the unsaturated tailings zone. These values are similar to the pH values found in the surface water ditches and much lower than values found below the water table.

Data to date indicate that horizontal movement of water in the unsaturated zone may be much greater than vertical movement. This, combined with large fluctuations of the seepage face and large changes in volume of water discharging from this face during precipitation events shows the need for more detailed work in the following areas:

1) <u>More detailed recharge-infiltration determination</u>

Surface water discharge and precipitation events should be monitored in conjunction with water table and water pressure fluctuations especially during precipitation events to better define the discharge of surface water (i.e. what percentage is groundwater from storage).

2) <u>Detailed examination of the seepage face and the unsaturated-saturated zone area along the tailings dam.</u>

Tensiometers and suction lysimeters should be installed to examine the changes in the water table and hydraulic pressures in response to precipitation events. Variations in water

chemistry should be examined during this time as precipitation events appear to cause the largest contribution of groundwater to surface water and will be important with respect to the migration of acidic water. Stream flow chemistry could be examined at the same time. Because the seepage face fluctuates so rapidly and there is a large increase in porewater discharge this will be of key importance in studying acid water migration.

3) Detailed examination of unsaturated zone and water table response to precipitation events on the main tailings.

Because the pH of water in the unsaturated zone is much lower than below the water table it will be important to determine whether this difference is chemically or hydraulically controlled. Solid sampling to date indicates that in some areas where the water table is deep (i.e. greater than 5m) there are a number of unsaturated and saturated layers above the water table. The saturated layers are the low hydraulic conducivity slimes and these may prevent any substantial amount of infiltration to the water table which may be the reason for high pH water below the water table.

Monitoring of the water table and the unsaturated zone during precipitation events, at intervals between the low hydraulic

conductivity layers will determine how much water is actually infiltrating to the watertable. This could be done at several test sites with varying depth to water and varying hydraulic conductivity.

Geophysical methods may also be utilized to enhance these investigations. A formation (tailings) conductivity with a disposable E log can be used. The disposable E log (Greenhouse et.al., 1985) is installed by vibration and samples both water and formation conductivities at 10 centimeter intervals. The device allows monitoring of conductivity variations with time.

APPENDIX A

Borehole Logs

BOREHOLE No. WA2

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST RJB
DATE OCTOBER 17, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
		CLAYEY SILT FILL - Very fine layers, some oxidized zones				
		TAILINGS - Wet, black fine-grained very cohesive (slimes) - oxidized - unoxidized interface at contact				
2		med. to fine sand 1.2 - 2.1 m				
4						
6						
		PEAT - black to brown, woody				
		CLAYEY SANDY SILT wet, stoney oxidized zones				
		BEDROCK - borehole terminated				
8						

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA23

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE U.S. Auger

GEOLOGIST RJB
DATE OCTOBER 18, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
		CLAY FILL				
		TAILINGS wet black fine-grained cohesive (slimes)				
2						
		PEAT brown, fibrous and woody				
		CLAYEY SILT wet stoney some layering				
		BEDROCK borehole terminated				
4						
6						

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA17

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST RJB
DATE OCTOBER 18, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/11	SAMPLES %RECOVERY	GROUNDWATER MONITORS
		TAILINGS Alternating fine sand and slime layers to 7.3 m saturated 3.3 m high metal content 3.7 m - 11.0 m				
5		saturated fine sand, slightly cohesive to 11.0 m				
10		PEAT AND CLAY some roots present CLAY gray and reddish brown grading to bluish gray, soft, varved				
15		silty from 11 - 13 m				
		Borehole terminated				
20						

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA18

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. Auger

GEOLOGIST RJB
DATE OCTOBER 19, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
5		TAILINGS Alternating fine sand and slime layers, decreasing slime layers with depth oxidized zones to 4 m saturated high metal content to 12.80 m				
10						
15		PEAT dark brown, fibrous CLAY gray to reddish-brown grading to bluish gray, soft, varved, very uniform				
20		Borehole terminated				

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA19

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST R.IB
DATE OCTOBER 20, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/11	SAMPLES %RECOVERY	GROUNDWATER MONITORS
		TAILINGS dark brown, sandy, very high metal content - oxidized to 1.0 m - saturated 1.5 m				
2						
4						
6						
		PEAT dark brown, woody CLAY dark brown to gray soft varved clay				
8						
10						
12						
14		Bedrock at 15.8 m				

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA9

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST RJB
DATE OCTOBER 20, 1985
ELEVATION

DEPTH	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
2		TAILINGS dark brown to black, fine grained cohesive (slimes), high metal content -oxidized to .3 m -saturated 0.5 m				
4						
6						
8		PEAT dark brown, woody CLAY gray to reddish brown, mottled layered, breaks up easily BEDROCK, borehole terminated				

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA20

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST RJB
DATE OCTOBER 21, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
2		TAILINGS Brown to black, sandy, slightly cohesive, high metal content oxidized zones to 4 m -saturated				
4						
6		PEAT AND WOOD FIBERS CLAY gray to brown, mottled, layered				
8		Borehole terminated				
10						

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA21

PROJECT WAITE-AMULET TAILINGS
CLIENT NORANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST RJB
DATE OCTOBER 21, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
		TAILINGS reddish brown to brown, sandy, uncohesive, high metal content				
		oxidized zones to 2.1 m				
2		-saturated				
		-almost all metals, layered				
4						
6		-some wood fibers and slime layers				
		PEAT dark brown, woody				
		CLAY gray to brown, mottled, layered				
		Borehole terminated				
8						
10						

TERRAQUA INVESTIGATIONS LTD.

BOREHOLE No. WA22

PROJECT WAITE-AMULET TAILINGS
CLIENT NOR ANDA
BOREHOLE TYPE H.S. AUGER

GEOLOGIST RJB
DATE OCTOBER 21, 1985
ELEVATION

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLES TYPE	SAMPLES BLOWS/ft	SAMPLES %RECOVERY	GROUNDWATER MONITORS
		TAILINGS dark brown to black, sandy, slightly cohesive, layered, high metal content, some small slime layers				
2						
		oxidized zones to 5m				
4						
6		-satur ated				
8						
10						
		PEAT dark brown, fibrous				
		CLAY dark brown to gray, soft, layered				
12						
		Borehole terminated				
14						

TERRAQUA INVESTIGATIONS LTD.

APPENDIX B

Water Level Data

GROUNDWATER LEVELS

WELL NUMBER	ELEVATION OF TOP OF CASING	ELEVATION OF WELL SCREEN	SEPT 6	SEPT 7	SEPT 8	OCT 14	(late) OCT 15	OCT 16	OCT 18	OCT 23
WA1-1	26.33		22.76	23.02		23.55				23.62
WA1-2	25.62		24.32	24.22		24.12				24.17
WA2-1	24.25		18.35	18.79		20.80				20.48
WA2-2	24.09		22.19	22.35		22.81				22.78
WA2.3	24.20						20.09	21.08	21.20	21.26
WA2-4	24.25						20.76	21.34		21.91
WA3-1	25.85		22.75	23.13	23.28	23.22				23.34
WA3-2	25.85		23.78	23.87	23.81	23.68				23.77
WA4-1	19.35		16.38	16.63	16.89	17.62				16.45
WA4-2	20.84		18.99	18.97	18.93	18.94				19.07
WA5-1	25.70		22.91	23.44	23.70	23.90				23.93
WA5-2	25.71		23.53	23.78	23.90	24.10				24.00
WA6-1	24.83		22.48	22.87	22.96	23.23				23.25
WA7-1	24.78		22.97	22.97	22.93	22.92				23.04
WA8-1	25.57		18.22	18.88	19.64	23.37				21.67
WA8-2	25.47		22.50	22.93	23.23	23.85				23.77
WA9-1	25.73		18.68	19.34	20.26	22.96				21.53
WA9-2	25.72		23.22	23.74	23.95	24.14				24.15
WA9-3	25.73						20.07	21.11		22.80
WA9-4	25.69						21.42	22.31		23.53
WA9-5	25.73						23.55	23.90		24.05
WA9-6	25.88									22.57
WA10-1	25.72		21.10	23.00		23.49				23.62
WA10-2	25.76		23.81	23.76		23.72				23.87
WA11-1	26.91		19.94	21.90		22.35				22.27
WA11-2	26.92		21.33	22.70		22.75				22.80
WA11-3	26.88					23.07				23.13

GROUNDWATER LEVELS

WELL NUMBER	ELEVATION OF TOP OF CASING	ELEVATION OF WELL SCREEN	SEPT 8	OCT 14	OCT 15	OCT 16	OCT 19	OCT 20	OCT 22	OCT 23
WA12-1	19.93		18.02	17.95						17.94
WA13-1	19.87		18.46	18.51						18.53
WA14-1	22.66		20.58	20.64						20.63
WA15-1	25.76				19.99	19.86				19.97
WA15-2	25.74				21.01*					21.02*
WA16-1	27.97									20.29*
WA17-1	26.43				22.00	22.02				22.18
WA17-2	26.42				22.30	22.29				22.33
WA17-3	26.40				22.37	22.34				22.36
WA17-4	26.44									22.38
WA17-5	26.38									22.31
WA17-6	26.57									19.29
WA18-1	27.87							18.43	18.37	18.42
WA18-2	27.80						19.74	20.74	21.06	20.79
WA18-3	27.78						20.27	21.08	21.10	21.04
WA18-4	27.89						20.53	21.14	21.51	21.17
WA18-5	27.87						20.81	21.22	21.56	21.23
WA19-1	21.00							16.55		18.10
WA19-2	21.16									18.09
WA20-1	23.15									19.71
WA20-2	23.25									19.74
WA21-1	21.67									18.31
WA21-2	21.44									18.35

GROUNDWATER LEVELS

WELL NUMBER	ELEVATION OF TOP OF CASING	ELEVATION OF WELL SCREEN	OCT 22	OCT 23
WA22-1	28.40		21.94	21.97
WA22-2	28.39		21.94	22.00
WA22-3	28.30		21.90	22.00
WA22-4	28.40		21.95	21.97

Elevations of Surface Water Locations

Location	Elevation
Top of bench where seeps occur below WA12	18.07
Bottom of bench where seeps occur below WA12	17.57
Ponded water below WA12	16.18
Water level in ditch below WA12	15.37
Water level of swamp west of the main road (SW8)	16.34
Water level in ditch west of the main road (SW7)	14.70
Clay-peat contact in the ditch (SW7)	15.29
Ditch on east side of road (between WA20-WA21)	16.16
Ditch below WA4-1	16.55
Middle of seepage at WA4-1	18.17
Head of the west flowing ditch near WA14	19.38
Seeps east of WA14	20.44
East ditch south of the centre of the tailings	19.43
Seeps off the centre area of the tailings (east of WA14)	20.03
Seeps south of WA19 (45m)	17.23
Seeps 45m north of WA19 off the first bench	17.70
Ditch east of the above seeps	15.06
Ditch directly east of WA19	16.50
Seeps southeast of WA13	16.74
Seeps 7m east of Wa13 (blackened grass)	17.60

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APPENDIX D

MONTHLY PROGRESS REPORT

JUNE 1985 - FEBRUARY 1985

Centre de Recherche Noranda
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noranda

9 October 1985

Mrs. Maureen Brock
Science Contracting Officer
Science and Professional Services Directorate
Department of Supply and Services
Place du Portage
Phase III, 11CL
11 Laurier Street
Hull, Quebec
K1A 0S5

SUBJECT : PROGRESS REPORT
MONTH : JUNE-JULY
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER: 0SQ85-00101

A contract has been issued on 2 July 1985 to Noranda Research Centre by DSS to undertake a hydrogeochemical investigation of reactive sulphide tailings at the Waite Amulet tailings site, Noranda, Quebec.

A site visit by N. Dave, Scientific Authority, E. Joe, Program Manager and C. Lim of CANMET and R. Siwik, K. Wheeland and W. Bawden of Noranda Research, reviewed the proposed detailed scope of work for the preliminary reconnaissance program and preliminary drilling program.

The terms of reference for the drilling program were submitted to the following four consultants to request for bids on 26 July 1985:

Gartner Lee Assoc. Ltd, Toronto
Terraqua, Waterloo
Lupien, Rosenberg, Journeaux & Assoc., Lachine
Site Investigation Services, Peterborough

Yours truly,

Richard S. Siwik

cc: Dr. N.K. Dave (3)
K.G. Wheeland/N-8523B

Encl.

Supply and Services Canada / Approvisionnements et Services Canada

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: Hydrogeochemical investigation of reactive sulphide tailings at the Waite Amulet tailings

CONTRACTOR – ENTREPRENEUR: Noranda Research Centre

2350.23440-5-9120

03085-00101

TASK DESCRIPTION / DESCRIPTION DE LA TÂCHE	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr		TASK COST – COÛT DE LA TÂCHE		
Preliminary Reconnaissance															
- Geophysics													10.0	0	10.0
- Water table eval.													5.0	0	5.0
- Water analysis													0	0	0
Preliminary Drilling															
- Instal piezometer													30.0	0	30.0
- Core samples													10.0	0	10.0
- Physical/Chemical/ bacterial analysis													0	0	0
Reporting													45.0	5.43	94.57
PLANNED COST BY MONTH / COÛT PRÉVU POUR CHAQUE MOIS	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	5.0	5.0		100.0		
GOV. REQUIR. / A.V.C. BY MONTH / PRÉVISIONS POUR CE MOIS	1.03	4.40												5.43	94.57

Note: (costs are reported in $1,000)
Project costs are shared 50% Noranda, 50% DSS

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9 October 1985

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K1A 0S5

SUBJECT : PROGRESS REPORT
MONTH : AUGUST
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER: 0SQ85-00101

Proposals for the 1985 Waite Amulet drilling program were received from Gartner Lee Assoc., Lupien, Rosenberg, Journeaux et Associes., and Terraqua Investigations. Site Investigations Services declined to bid on this project. Terraqua Investigations was awarded the contract.

A meeting was held in Toronto on 21 August, 1985 with N. Dave, Scientific Authority, R. Siwik, project leader and R. Blackport of Terraqua Investigations to review recommended modifications in the terms of reference. It was agreed that approximately 30 well tip piezometers would be installed and monitored for pH and Conductivity during the preliminary reconnaissance. The geophysics will still be performed as per the terms of reference.

Geophysics will commence during the first week of September to assess bedrock location, plume detection and high reactive zones in the tailings.

Yours truly,

Richard S. Siwik

cc: Dr. N.K. Dave (3)
K.G. Wheeland/N-8523-B

Encl.

Supply and Services Canada / Approvisionnements et Services Canada

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: Hydrogeochemical investigation of reactive sulphide tailings at the Waite Amulet tailings

CONTRACTOR – ENTREPRENEUR: Noranda Research Centre

23SQ.23440-5-9120	09085-00101

TASK DESCRIPTION / DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS												TASK COST – COÛT DE LA TÂCHE		
	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr				
Preliminary Reconnaissance															
- Geophysics													10.0	0	10.0
- Water table eval.													5.0	0	5.0
- Water analysis													0	0	0
Preliminary Drilling															
- Instal piezometer													30.0	0	30.0
- Core samples													10.0	0	10.0
- Physical/Chemical/ bacterial analysis													0	0	0
Reporting													45.0	11.09	33.91
PLANNED COST BY MONTH – COÛT PRÉVU POUR CHAQUE MOIS	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	5.0	5.0		100.0		
ACT. PAYMENT / P.V.E. BY MONTH – PROVISION POUR CE MOIS	1.03	4.40	5.66											11.09	88.91

D4

Note: (costs are reported in $1,000)
Project costs shared 50% Noranda, 50% DSS

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9 October 1985

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SUBJECT : PROGRESS REPORT
MONTH : SEPTEMBER
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER: 0SQ85-00101

Preliminary reconnaissance commenced 4 September 1985. Installation of the 30 well point piezometers required 10 mandays.The pH range in the tailings was 4-6 and three major zone of high conductivity were detected which correlated with the EM 34 conductivity readings.

The seismic survey indicated a bedrock ridge extending under the tailings from the northeastern outcrop which may act as a porewater boundary layer. The seismic survey also indicated a 30 foot clay layer underlying the main tailings dam. The geophysics field program required 16 mandays.

A meeting was held in Toronto with N. Dave, Scientific Authority, R. Blackport and P. Pehme of Terraqua and R. Siwik to discuss the results of the preliminary reconnaissance. With the unexpected high pH in the tailings mass and the extensive clay layer under the tailings dam, the detailed drilling program will focus on the three anomolies indicated by the geophysics, the bedrock ridge and the dam face areas. The off tailings sites will be reduced from four to three piezometer sites.

A meeting was held with Dr. G. Ferronni to dicuss the possibility of Laurentian University providing bacterial counts (cells per gm dry weight) for Thiobacillus ferrooxidans and sulfate-reducing bacteria for twenty five core samples.

The Falconbridge operation was visited on the 23 September to review their Reactive Tailings projects.

The detailed drilling program is expected to commence in early October 1985.

Yours truly,

Richard S. Siwik

cc: Dr. N.K. Dave (3)
K.G. Wheeland/N-8523-B

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9 October 1985

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SUBJECT : PROGRESS REPORT
MONTH : OCTOBER
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER: 0SQ85-00101

The 1985 drilling program commenced on the 17 October 1985 with a total of 55 piezometers installed in 23 locations of which 9 were core sampled. The location of the 22 piezometer nests is illustrated in Figure 1. The depth to the piezometer screen, water level from ground surface, pH and Conductivity for each piezometer is detailed in Table 1.

The contract was amended by $5,000 to provide for Thiobacillus ferrooxidans and sulfate-reducing bacteria on twenty five core samples.The work will be performed by Dr. G. Ferroni of Laurentian University and the total cost ($5,000) will be billed to CANMET. This work is to be performed on core samples from site PWA-20 and PWA-22. C. Lim, CANMET, delivered the samples on route to Elliott Lake.

An on site review of the first few core samples indicated that the underlying clays were relatively impervious and the most of the seepage was probably exiting the toe of the dam.This indicated that installation of piezometers off the tailings dam would provide little information of the hydrogeochemistry of the tailings mass, therefore, emphasis was placed on core sampling and piezometer nest locations on the tailings dam proper.

Core samples (4 inch diameter) from 9 locaction were cut in 1 foot sections of which the first 9 inches was bagged as a reference sample and the remaining 3 inches were jarred and shipped to Elliot Lake via C. Lim,CANMET.

Mrs. Ann Brown, a PhD candidate from the University of Ottawa, Dr. Sukhu P. Mather, Agriculture Canada, and 2 associates visited the Waite Amulet site and other Noranda properties to collect muskeg samples for a CANMET funded project titled "Microbial Control of Tailings Dump Leaching".

The following is a schedule of activities for November:

Priority sequencing for pumping piezometers;
Collect water samples from 55 piezometers;
Preliminary indication of bacterial counts;
Draft report for field work.

Yours truly,
Centre de Recherche Noranda

Richard S. Siwik

cc: (3) Dr. N.K. Dave
Scientific Authority
Energy, Mines and Resources
CANMET, Mining Research Laboratories
Elliott Lake Laboratory
Elliott Lake, Ontario
K.G. Wheeland/N-8523-B

Encl.

RSS/vc

Supply and Services Canada / Approvisionnements et Services Canada

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: Hydrogeochemical investigation of reactive sulphide tailings at the Waite Amulet tailings

CONTRACTOR – ENTREPRENEUR: Noranda Research Centre

2350.23440-5-9120 | 00085-00101

TASK DESCRIPTION / DESCRIPTION DE LA TÂCHE	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr				
	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS														
Preliminary Reconnaissance													10.0	10.0	0
- Geophysics													5.0	5.0	0
- Water table eval.													0	0	0
- Water analysis															
Preliminary Drilling													30.0	4.4	25.6
- Instal piezometer													10.0	5.0	5.0
- Core samples													0	0	0
- Physical/Chemical/ bacterial analysis													5.0	0	5.0
Reporting													45.0	15.0	30.0
PLANNED COST BY MONTH / COÛT PRÉVU POUR CHAQUE MOIS	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	5.0	5.0		105		
ACT. / RÉAL. ACTUAL BY MONTH / RÉALISÉ PENDANT CE MOIS	1.03	4.40	5.66	8.11	20.1	39.4								39.4	65.6

Note: (costs are reported in $1,000)
Project costs shared 50% Noranda, 50% DSS
Contract amended in October; additional $5,000 to be paid totally by DSS.

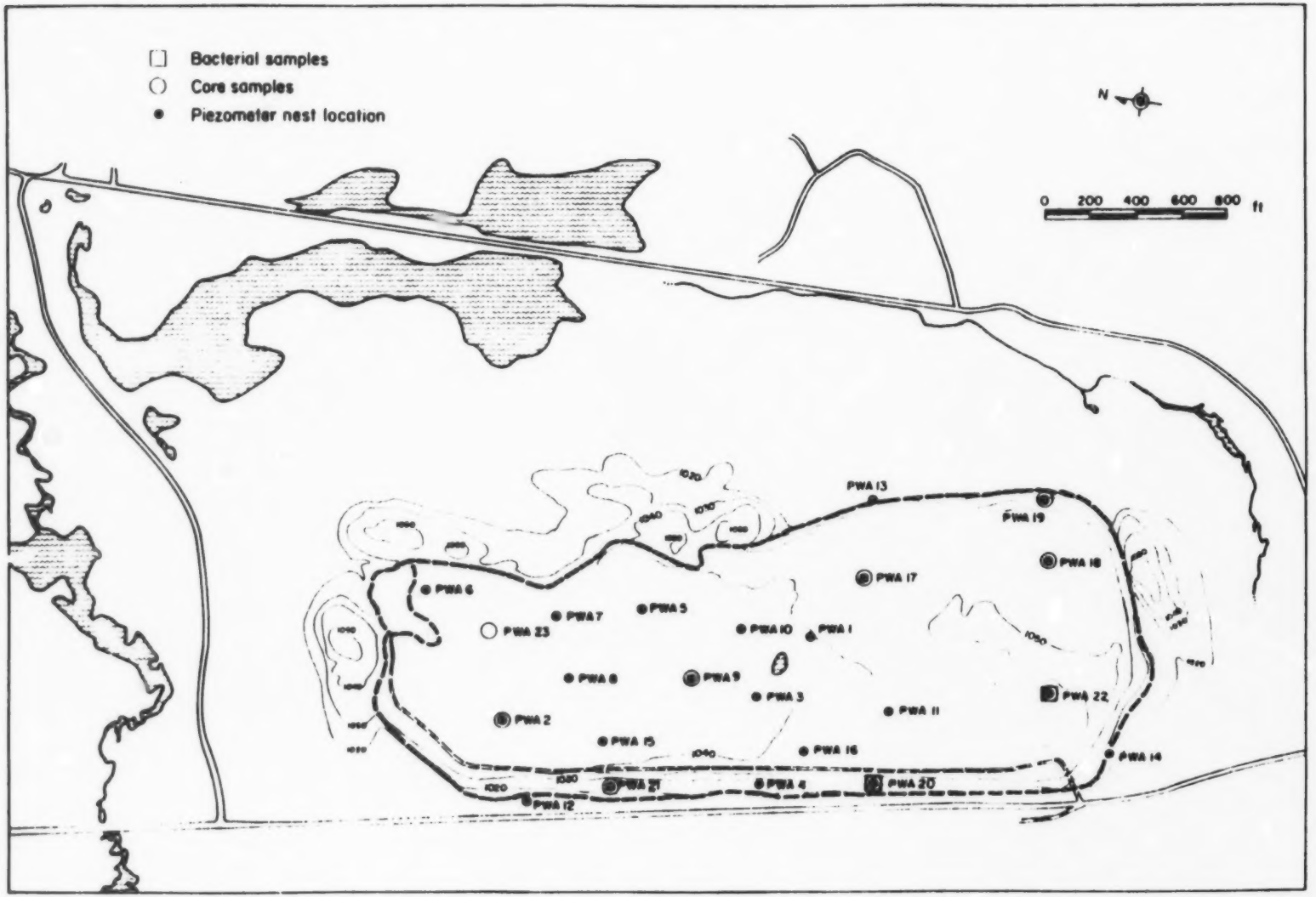

Figure 1 - Location of Piezometer Nests on Waite Amulet Tailings Site - 1985 Drilling Program

CENTRE DE RECHERCHE NORANDA

TABLE I

DEPTH, WATER LEVEL, pH AND ELECTRICAL CONDUCTANCE FOR WAITE AMULET PIEZOMETERS

Waite Amulet	Piezometer Depth (ft)	Water Level From Ground Surface	pH	Electrical Conductance uS/cm
PWA-1 -1	26.0	5.0	7.55	3,000
-2	8.0	3.0	7.55	5,120
PWA-2 -1	19.5	7.0	7.35	3,100
-2	5.0	1.5	7.80	6,060
-3	14.7	4.0	6.55	7,200
-4	9.8	3.5	7.45	6,100
PWA-3 -1	16.5	5.5	7.30	6,870
-2	6.5	4.0	7.35	2,520
PWA-4 -1	9.0	1.8	6.50	1,975
-2	4.5	4.0	4.75	7,890
PWA-5 -1	16.0	1.5	6.25	2,750
-2	5.5	1.0	6.45	11,930
PWA-6 -1	7.0	2.0	6.80	5,000
PWA-7 -1	8.0	3.0	6.55	6,440
PWA-8 -1	19.5	2.0	6.60	1,440
-2	5.0	0.5	7.50	6,650
PWA-9 -1	21.5	5.5	7.05	1,920
-2	5.0	2.0	7.05	3,790
-3	16.4	4.0	7.20	5,940
-4	11.4	3.0	7.40	7 900
-5	8.2	2.2	7.50	4,950
-6*	26-28	6.5	7.05	-
PWA-10-1	24.0	4.5	7.45	1,830
-2	5.0	4.0	8.15	2,400
PWA-11-1	27.0	11.5	6.60	2,960
-2	17.0	10.6	7.05	6,350
-3	10.0	9.5	5.60	6,200

TABLE I (Cont'd)

PWA-12-1	8.0	4.5	6.40	5,840
PWA-13-1	8.0	3.5	6.00	5,980
PWA-14-1	5.0	1.0	5.30	8,210
PWA-15-1	21.0	14.5	7.25	5,090
-2	11.0	10.8	-	-
PWA-16-1	20.0	19.8	-	-
PWA-17-1	25.0	10.5	7.00	5,740
-2	19.4	9.5	6.90	7,420
-3	14.7	9.5	7.20	7,620
-4	11.3	9.5	-	-
-5	14.0	9.5	-	-
-6*	49-59	-	-	-
PWA-18-1*	49-59	-	-	-
-2	36.5	18.5	7.05	4,230
-3	31.0	18.0	7.25	5,940
-4	25.5	17.5	7.20	6,910
-5	21.0	17.5	6.65	7,160
PWA-19-1	19.0	6.5	7.00	3,200
-2	8.0	6.5	6.10	10,230
PWA-20-1	16.0	8.0	6.55	1,250
-2	8.0	7.5	6.05	9,000
PWA-21-1	16.0	7.5	6.90	5,150
-2	9.5	7.5	6.95	7,100
PWA-22-1	36.0	19.0	7.15	3,670
-2	30.5	19.0	7.40	4,000
-3	26.5	19.0	7.15	7,500
-4	25.0	19.0	7.05	7,640
PWA-23	core sample only			

* Screened wells in clay

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16 December 1985

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SUBJECT : PROGRESS REPORT

MONTH : NOVEMBER

DSS FILE NUMBER : 23SQ.23440-5-9120

DSS CONTRACT SERIAL NUMBER : 0SQ85-00101

D. Blowes, a PhD candidate at University of Waterloo, has taken a 1.8 and 4.0 m core sample adjacent to piezometer nest PWA-2 and PWA-22, a fine and coarse section of the tailings dam, respectively. Porewater samples were taken from core samples. (This work is funded by the Noranda Bradfield Scholarship.) The Heath Steele site was visited in conjunction with piezometer installations by D. Blowes. Piezometers were installed in the same location as work done by RPC, New Brunswick, in the early 1970's.

A priority pumping schedule for the piezometers has been issued. The following is a schedule of activities for December:

- Collect water samples from 54 piezometers.
- Review draft report of field work.
- Review results of bacterial counts performed by Laurentian University.

..../2

- Assess analytical results of core samples performed by CANMET.
- Assess analytical results of porewater performed by CANMET.

Yours truly,

CENTRE DE RECHERCHE NORANDA

Richard S. Siwik

cc: (3) Dr. N.K. Dave
Scientific Authority
Energy, Mines and Resources
CANMET, Mining Research Laboratories
Elliott Lake Laboratory
Elliott Lake, Ontario

K.G. Wheeland/N-8523-B

Enclosures

RSS/sp

Supply and Services Canada — Approvisionnements et Services Canada

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: Hydrogeochemical investigation of reactive sulphide tailings at the Waite Amulet tailings

CONTRACTOR – ENTREPRENEUR: Noranda Research Centre

2190.2(440-5-9120)

(23)05-00101

	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr				
Preliminary Reconnaissance													10.0	10.0	0
- Geophysics													5.0	5.0	0
- Water table eval.													0	0	0
- Water analysis															
Preliminary Drilling													30.0	22.0	8.0
- Instal piezometer													10.0	5.0	5.0
- Core samples													0	0	0
- Physical/Chemical/ bacterial analysis													5.0	0	5.0
Reporting													45.0	21.8	23.2
	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	5.0	5.0		105		
	1.03	4.40	5.66	8.11	20.1	24.5								63.8	41.2

Note: (costs are reported in $1,000)
Project costs shared 50% Noranda, 50% DSS
Contract amended in October; additional $5,000 to be paid totally by DSS.

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24 January 1986

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Science Contracting Officer
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SUBJECT : PROGRESS REPORT
MONTH : DECEMBER 1985
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER: 0SQ85-00101

During the first week of December a number of the Waite Amulet piezometers were blown out with nitrogen and samples were collected on only 10 of the 55 wells, as problem were encountered with the pumping lines freezing. The 10 samples were filtered, measured for pH, conductivity, alkalinity and acidity in the Noranda, Horne Division Laboratory. Metal determinations will be undertaken at CANMET Elliot Lake Laboratory. The field data are found in Table 1.

A copy of ' Quantification of Thiobacillus Ferrooxidans and sulfate-reducing bacteria in core samples from the Waite Amulet tailings ' has been forwarded to N. Dave. T. ferroxidans were predominant in upper 2 m of both core samples WA-20 and WA-22.

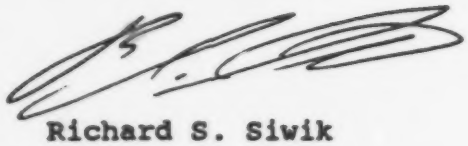
The following is a schedule of activities for January 1986:

Parts

Called J. B. 4/2/86.

- Finalized report of field program.
- Analysis of porewater samples by CANMET.
- Analysis of minimum 10 core samples by CANMET.

Yours truly,



Richard S. Siwik

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TABLE I
WAITE AMULET FIELD NOTES

Waite Amulet	Piezometer Depth (ft.)	Water Level (M)	Blowing Date	Water Level From Top of Piezometer (M)	Sampling Date	pH	Electrical Conductance (uS) FIELD/LAB	Eh mV	Temp °C FIELD/LAB	Alk. mg/L	Acid mg/L
PWA-2-1	19.5	6.96	05/12/85	3.40	05/12/85	6.8	3,080	0	18	160	44
-2	5.0	2.52	"	1.50							
-3	14.7	5.17	"	3.02							
-4	9.8	3.86	"	2.52							
PWA-3-1	16.5	6.14	"	2.74							
-2	6.5	3.09	"	2.26							
PWA-4-1	9.0	4.06	"	1.70							
-2	4.5	2.14	"	1.82							
PWA-9-1	21.5	7.86	05/12/85	2.70							
-2	5.0	2.65	"	1.43							
-3	16.4	6.13	"	2.53							
-4	11.4	4.61	"	2.11							
-5	8.2	3.21	"	2.06							
-6	26.28	5.69	"	3.46							
PWA-11-1	27.0	8.64	05/12/85	4.47	05/12/85	7.0	2,100 / 2,950	-30	4 / 15.5	90	40
-2	17.0	6.17	"	4.03	"	6.8	4,900 / 5,800	-2	6 / 16.5	90	336
-3	10.0	3.99	"	3.60	"	5.5	- / 8,000	+60	- / 18.0	-	5,400
PWA-15-1	21.0	7.67	05/12/85	5.77							
-2	11.0	4.61	"	DRY							
PWA-20-1	16.0	6.14	05/12/85	3.43	05/12/85	7.52	1,250	+160	16	500	40.0
-2	8.0	4.06	"	3.49	"	6.28	6,700	+50	17	44	11.28
PWA-22-1	36.0	11.70	05/12/85	6.51	05/12/85	7.0	2,500	-55	25	530	139.2
-2	30.5		"	6.48	"	7.0	2,200 / 3,600	-50	5 / 21	184	54.0
-3	26.5		"	6.39	"	6.1	4,500 / 6,000	-20	5 / 21	40	598.2
-4	25.0	7.715	"	6.51	"	5.7	3,600 / 6,000	50	6 / 21	24	1.50 G (1500)

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT Hydrogeochemical investigation of reactive sulphide tailings at the Waite Amulet tailings

CONTRACTOR – ENTREPRENEUR Noranda Research Centre

2350-2(4410-3-9120)

	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr				
Preliminary Reconnaissance															
- Geophysics													10.0	10.0	0
- Water table eval.													5.0	5.0	0
- Water analysis													0	0	0
Preliminary Drilling															
- Instal piezometer															
- Core samples													30.0	22.0	8.0
- Physical/Chemical/ bacterial analysis													10.0	5.0	5.0
													0	0	0
Reporting													5.0	0	5.0
													45.0	26.4	18.6
	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	15.0			105	68.4	36.6
	1.03	4.40	5.66	8.11	20.1	24.5	4.55								

D-16

Note: (costs are reported in $1,000)
Project costs shared 50% Noranda, 50% DSS
Contract amended in October; additional $5,000 to be paid totally by DSS.

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24 February 1986

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11 Laurier Street
Hull, Quebec
K1A 0S5

SUBJECT : PROGRESS REPORT
MONTH : JANUARY 1986
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER : OSQ85-00101

A draft report entitled "A preliminary hydrogeological investigation of the Waite Amulet tailings" from Terraqua Investigations was received for review. A meeting was held at Noranda Research Centre to review the draft report with the author R. Blackport, Terraqua Investigations Ltd, N. Dave, CANMET, R. Siwik, W. Bawden and H. Veldhuizen of Noranda. The final report is expected at the end of February 1986.

The following is a schedule of activities for February 1986:

- Final report for field program.
- Presentation to RATS program on 1985 results and proposed 1986 program.
- Analysis of porewater samples by CANMET.
- Analysis of minimum of 10 core samples by CANMET.

Yours truly,

Richard S. Siwik

cc: (3) Dr. N.K. Dave
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Energy, Mines and Resources
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Hydrogeochemical investigation of reactive sulphide tailings at the White Amulet Tailings

Norandra Research Centre

	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr				
Preliminary Reconnaissance															
- Geophysics												10.0	10.0	0	
- Water table eval.												5.0	5.0	0	
- Water analysis												0	0	0	
Preliminary Drilling															
- Instal piez. - tev															
- Core samples												30.0	22.0	8.0	
- Physical/Chemical/ bacterial analysis												10.0	5.0	5.0	
												0	0	0	
Reporting												5.0	0	5.0	
												45.0	30.2	14.8	
	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	15.0		105			
	1.03	4.40	5.66	8.11	20.1	24.5	4.55	3.78					72.2	32.8	

D-21

Note: (costs are reported in $1,000)
Project costs shared 50% Norandra, 50% DSS
Contract amended in October; additional $5,000 to be paid totally by DSS.

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13 March 1986

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SUBJECT : PROGRESS REPORT
MONTH : FEBRUARY
DSS FILE NUMBER : 23SQ.23440-5-9120
DSS CONTRACT SERIAL NUMBER : OSQ185-00101

A meeting was held in Ottawa, 9 January 1986, to establish a Steering Committee and technical working group for the Reactive Tailings Program. The steering committee executive will consist of F. Frantisak, Noranda Inc., E. Joe, CANMET and J. Hawley, Water Resources Branch, Ontario. The Technical Working Group will consist of mainly industry and governments project leaders and technical support from interested parties.

A Noranda Tailings Task Force Committee meeting was held in Toronto, 5-6 February 1986, to review the 1985 results of the Waite Amulet tailings work and proposed 1986 programs recommended for funding to the Reactive Tailings Program. Revisions in the 1986 scope of work at the Waite Amulet emphasized evaluation of the oxidation control mechanisms for 1986 with a view to field applications in 1987.

The Technical Working Group for Reactive Tailings program met in Ottawa on 13-14 February, 1986 to review and ratify the technical objectives and proposed research areas of the program. Noranda requested funding in the following areas:

- Continuing the hydrogeochemical investigation of the Waite Amulet tailings.
- Control of reactive tailings dusting at BMS-M.
- Reduction of acid generation from reactive waste rock with the use of bactericides (in the lab and at BMS-M No.6 site).

A copy of the presentation to the RATS program is attached.

Planned for next month:

1. Presentation for funding of Noranda's tailings related research projects to Reactive Tailings Program Technical Working Group on 5-6 March 1986.

2. Finalize 1985 Waite Amulet field report.

3. Analysis of porewater samples by CANMET.

4. Analysis of 10 core samples by CANMET.

Yours truly,
Noranda Research Centre

Richard S. Siwik

RSS/vc

cc: (3) Dr. N.K. Dave
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Energy, Mines and Resources
CANMET, Mining Research Laboratories
Elliott Lake Laboratory
Elliott Lake, Ontario

K.G. Wheeland/N-8523-B

Encl.

Hydrogeochemical investigation of reactive sulphide tailings at Un Unit Area, Quirke
Norandа Research Centre

	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr			
Preliminary reconnaissance														
- Geophysics														
- Water table eval.												10.0	10.0	0
- Water analysis												5.0	5.0	0
Preliminary Drilling												0	0	0
- Instal piezometer														
- Core samples														
- Physical/Chemical/ bacterial analysis												30.0	30.0	30.0
												10.0	10.0	10.0
												0	0	0
Reporting												5.0	5.0	5.0
-														
-												49.0	34.0	11.0
	1.0	5.0	5.0	45.0	5.0	10.0	9.0	5.0	5.0	15.0				
	1.03	4.40	5.66	9.11	20.1	24.5	4.55	3.78	21.8			103		
													94.0	11.0

Note: (costs are reported in $1,000)
Project costs shared 50% Norandа, 50% DSS
Contract amended in October; additional $5,000 to be paid totally by DSS.

PRESENTATION TO RATS TECHNICAL WORKING GROUP

by

Noranda Research Centre
240 Hymus Blvd.
Pointe Claire, Quebec
H9R 1G5

13-14 February 1986
Ottawa, Ontario

1. INTRODUCTION

The following research topics are submitted for 1986 funding within the reactive tailings program:

- Hydrogeochemical investigation of the Waite Amulet reactive tailings ($225,000)
- Control of reactive tailings dusting ($ 70,000)
- Reduction of acid generation from reactive waste rock with the use of bactericides ($ 60,000)

It is felt that these research topics will provide information on the development of improved long-term reactive tailings management practices.

2. HYDROGEOCHEMICAL INVESTIGATION OF THE WAITE AMULET REACTIVE TAILINGS

2.1 History of the Waite Amulet Tailings

The Waite Amulet tailings area, illustrated in Figure 1, is situated approximately 20 kilometres north of Noranda, Quebec ceased operation in 1962 leaving 6.5 million tons of reactive sulphide tailings in an elevated 100 acre main dam and tailings spills in a lower area.

Acid seepages from these tailings areas are collected in an acid water reservoir for treatment in a computer controlled treatment plant.

The Horne Division's first full scale attempts in the late 1960's were unsuccessful due to the high acidity of the tailings and revegetation techniques. These problems were eventually solved with the help of researchers from the University of Guelph.

The majority of the sulphide tailings dam was revegetated in 1978 and 1979. The pH of the surface tailings was raised to a neutral level with 20 tons per acre of agricultural limestone. Up to 1 ton per acre of fertilizer was used because these tailings were devoid of any nutrients. Birdsfoot trefoil (a legume which produces its own fertilizer) and a companion crop of creeping red fescue were planted. For the last 6 years, the lush vegetation that covers the abandoned Waite Amulet tailings has withstood the harsh environment and has not been re-treated with any fertilizers or limestone.

2.2 Study Objectives for the Waite Amulet Site

The overall objective of the Waite Amulet site is as follows:

To eliminate the need for perpetual maintenance and water treatment for reactive tailings areas via;

- the development of a better understanding of the biohydrogeochemical processes and controlling mechanisms;
- development of improved long-term tailings management practises based on this understanding.

To achieve these objectives, specific question must be addressed at the Waite Amulet tailings area. A baseline survey of the existing hydrogeology and geochemistry of the tailing area is

required. This will provide an indication of where the acid generation is occurring and the regulating factors, as a basis for developing control techniques.

2.3 Results of the 1985 Field Program

The 1985 Waite Amulet field program commenced in September. Figure 2 illustrates the 23 locations for the piezometer nests, location of core samples and bacterial samples taken during 1985. Geophysical methods concurrent with preliminary piezometer installations provided a skeletal look at the underlying geologic materials and their variation, saturated tailings porewater chemistry, hydraulic conductivity and direction of flow. From this, a piezometer network was designed and a total of 55 piezometers was installed. Core samples at 9 of the 23 piezometer nests were taken. Bacterial counts for Thiobacillus Ferrooxidans and sulphate-reducing bacteria were conducted on 2 of the 9 core samples.

Results indicate bedrock topography is extremely variable, especially in the northern section of the tailings area. The underlying clay is moderately irregular as it gently slopes south and west across the site with thickness varying from 2 m to 20 m. The tailings varies in thickness from 2 m to 15 m. The clay provides a good aquitard for tailings porewater which drains along the perimeter of the tailings dam. The northern section, where the interface between clay and bedrock is below the tailings, exhibits possible tailings porewater movement in an underlying gravelly lense. This area contributes a minimal volume compared to the total flow off the site.

The water table illustrated in Figure 3 is just below the tailings surface in the north and central portions and up to a depth of 5.5 m below ground surface in the southern portion. Hydraulic conductivities range from 9×10^{-7} to 1.4×10^{-3} cm/s. Low hydraulic conductivities were found in the fine grained northern section and along the lower central section of the tailings. Higher conductivities were detected in the southern section and along the tailings dam perimeter. The porewater horizontal velocities within the tailings range from 0.4 cm/y to 5 m/y. Tailings porewater velocities across the tailings dam may be up to 35 m/y indicating the majority of tailings porewater to exit the sides of the dam.

The pH and Electrical Conductance measurements on site illustrated in Figures 4-7 indicated pH to be generally above 6 below the water table. Based on pH determinations of the bacterial samples and work by D. Blowes, University of Waterloo,

pH increases with depth form ~3 to 6 in the unsaturated zone.

Analysis of samples for bacteria indicated the strong presence of T. Ferroxidans in the upper 2 m of tailings (8000>100000 MPN/g). Sulphate reducing bacteria were not detected in a majority of the samples below the water table.

Analysis of core samples for physical and chemical determinations are underway by CANMET. Analysis of the 10 piezometer samples taken in December are underway by CANMET.

2.4 Recommended 1986 Program

The 1986 program will emphasize hydrogeological uncertainties concerning the site, evaluate the geochemistry of the unsaturated zone and dam face, and assess oxidation control options for 1987.

2.4.1 Finalize Site Hydrogeology

A downward hydraulic gradient in the northern section indicates a possible hydraulic connection between the clay and the underlying rock. The flow direction of the saturated zone and seepage face will be firmed up.

2.4.2 Evaluate Geochemistry of Unsaturated Zone and Dam Face

An investigation of the biohydrogeochemical processes and controlling mechanisms of the unsaturated zone and dam face will be undertaken via:

- analysis of core samples and porewater samples in the unsaturated zone;
- monitoring of the oxygen profile;
- monitoring of metal loadings and flow through and out of tailings;
- monitoring of rainfall and evaporation.

2.4.3 Assess Oxidation Control Options for 1987

The Waite Amulet tailings has been revegetated by directly seeding into the tailings and vegetating a clay cover. This existing condition will in part provide information on their effectivenees as oxygen barriers. The use of wetlands along the northeastern edge will be considered as a control technique.

Additional options will be considered once the controlling mechanisms are well defined.

3. CONTROL OF REACTIVE TAILINGS DUSTING

Dusting of operating reactive tailings areas is a serious problem for mining companies. Cost-effective techniques are required to minimize the wind-borne distribution of dust from operating tailings areas with resultant nuisance and environmental contamination effects.

3.1 Study Objective

The objective will be to evaluate techniques for controlling fugitive dust emissions from reactive tailings areas.

3.2 Recommended 1986 Field Program at Brunswick Mining, No.12 Site, Bathurst, N.B.

A baseline survey will be conducted to evaluate the degree and extent of contamination by dust from BMS-M tailings. Based on preliminary 1985 results, an extensive survey will be undertaken to delineate metal levels in soil, water and vegetation. About 25 key stations will be set up to monitor a 25 km radius.

Dust control tests using chemicals and crimped straw techniques will be undertaken with dosages based on results of preliminary 1985 tests. Ten one-acre plots will be evaluated for a two-year peiod via continual visual monitoring to determine the durability of treatment techniques.

4. REDUCTION OF ACID GENERATION FROM REACTIVE WASTE ROCK

Reduction of bacterial acid generation will decrease the impact of reactive waste rock and should reduce the cost and duration of rehabilitation procedures.

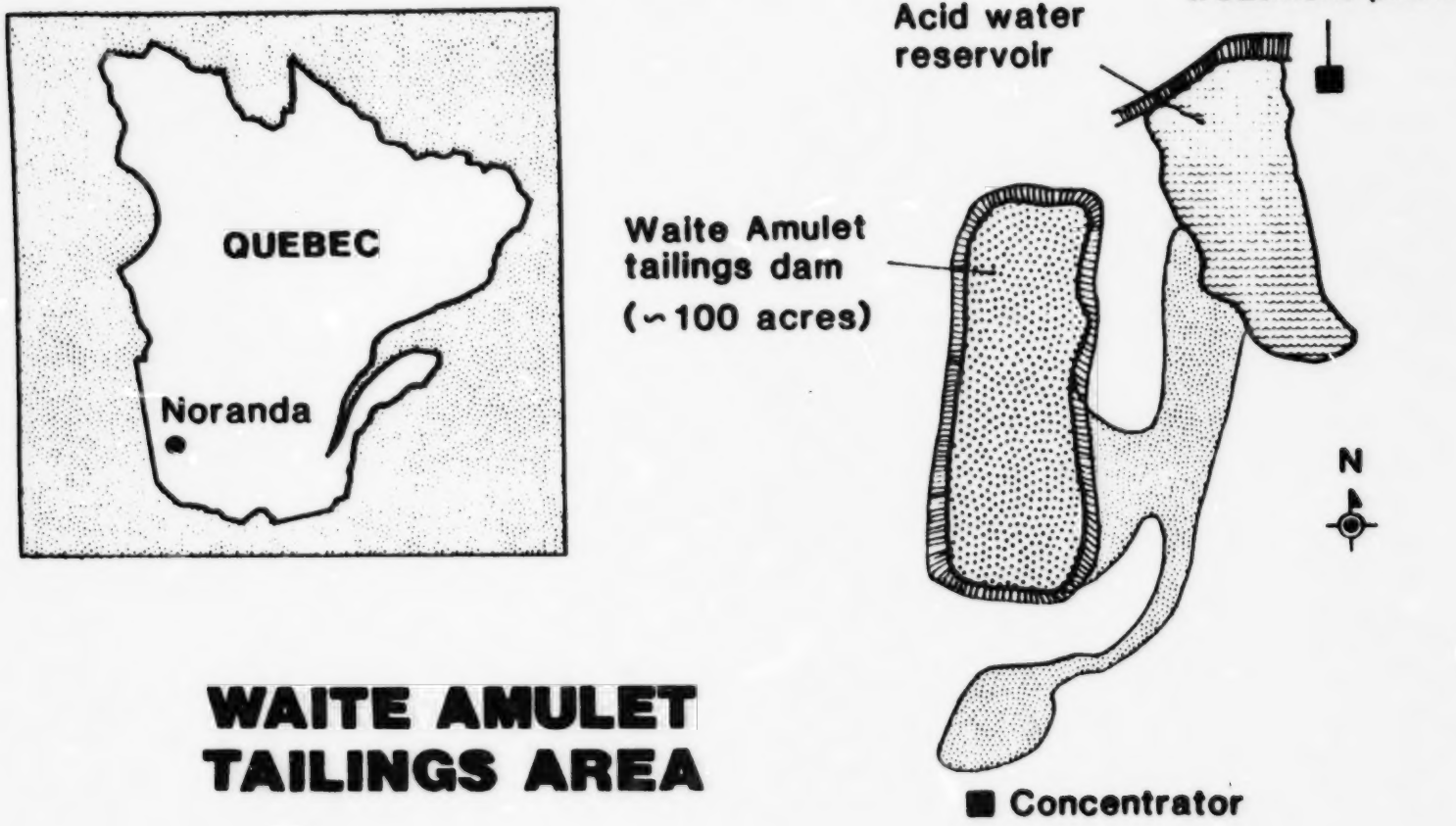
4.1 Study Objective

The study objective is to investigate and improve the effectiveness of bactericides in reducing acid generation from reactive waste rock.

4.2 Recommended 1986 Field Program at Brunswick Mining, No.6 Site, Bathurst, N.B.

The 1985 laboratory results illustrated in Figures 8-10, will indicate which bactericides are most effective in controlling acid generation or simulated waste rock.

It is envisaged that a small scale field trial will be conducted in the spring of 1986. Water quality will be monitored prior to and after application of the bactericide. A large scale trial (6 hectares) will be monitored before and after bactericide application to evaluate longer-term benefits.



WAITE AMULET TAILINGS AREA

Figure 1 - Waite Amulet Tailings Area

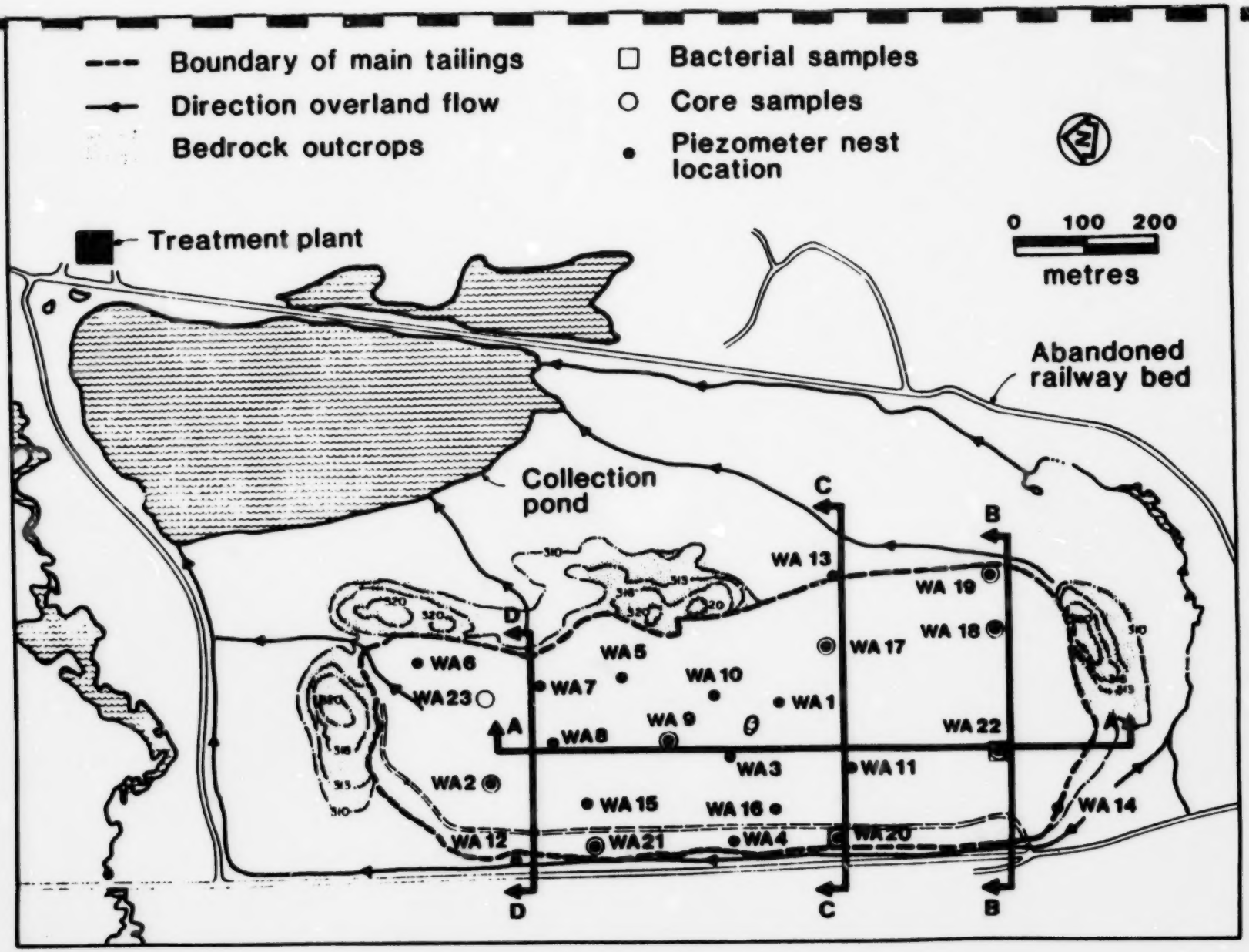


Figure 2 - **SAMPLING & PIEZOMETER LOCATIONS**

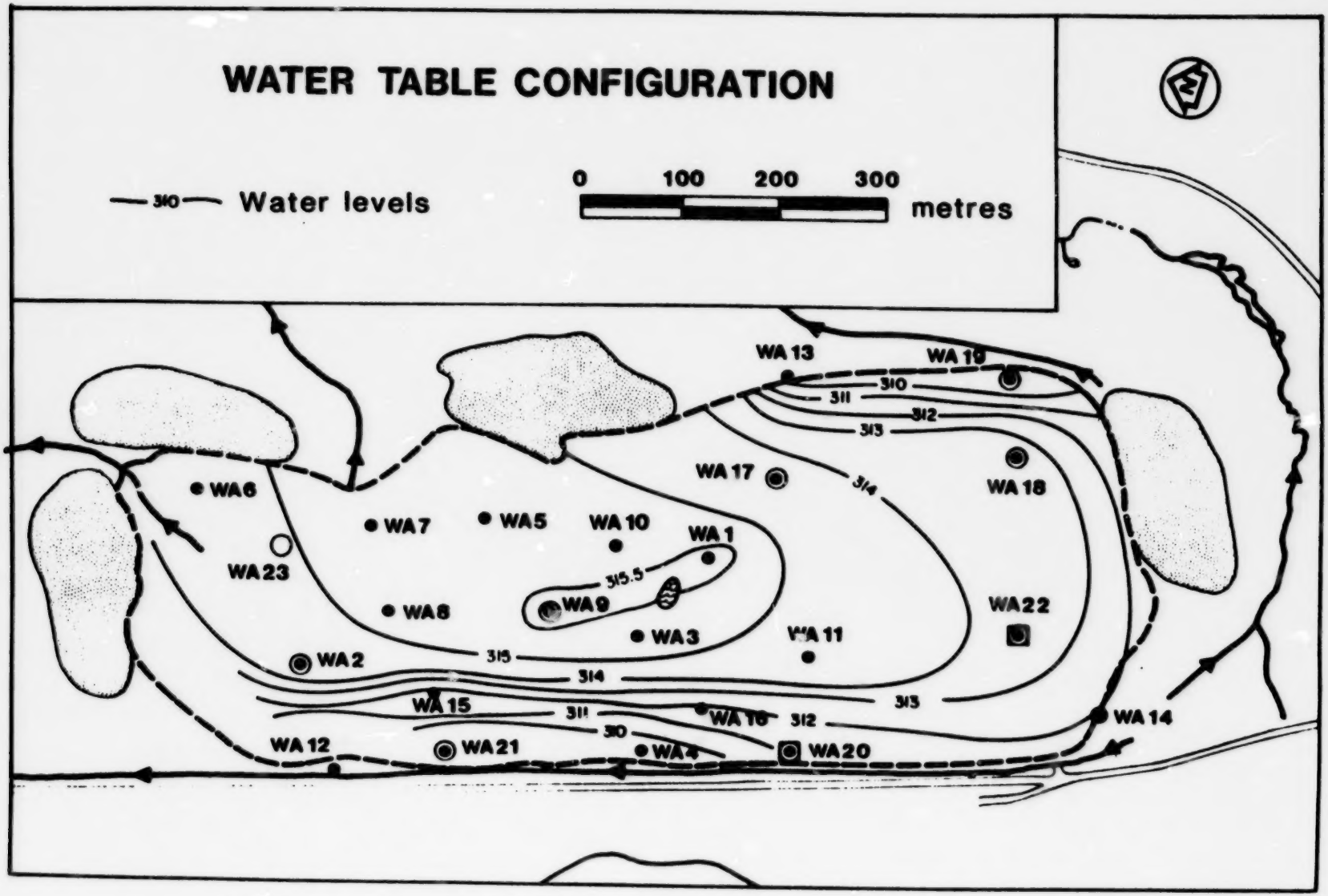


Figure 3 - Water Table Configuration

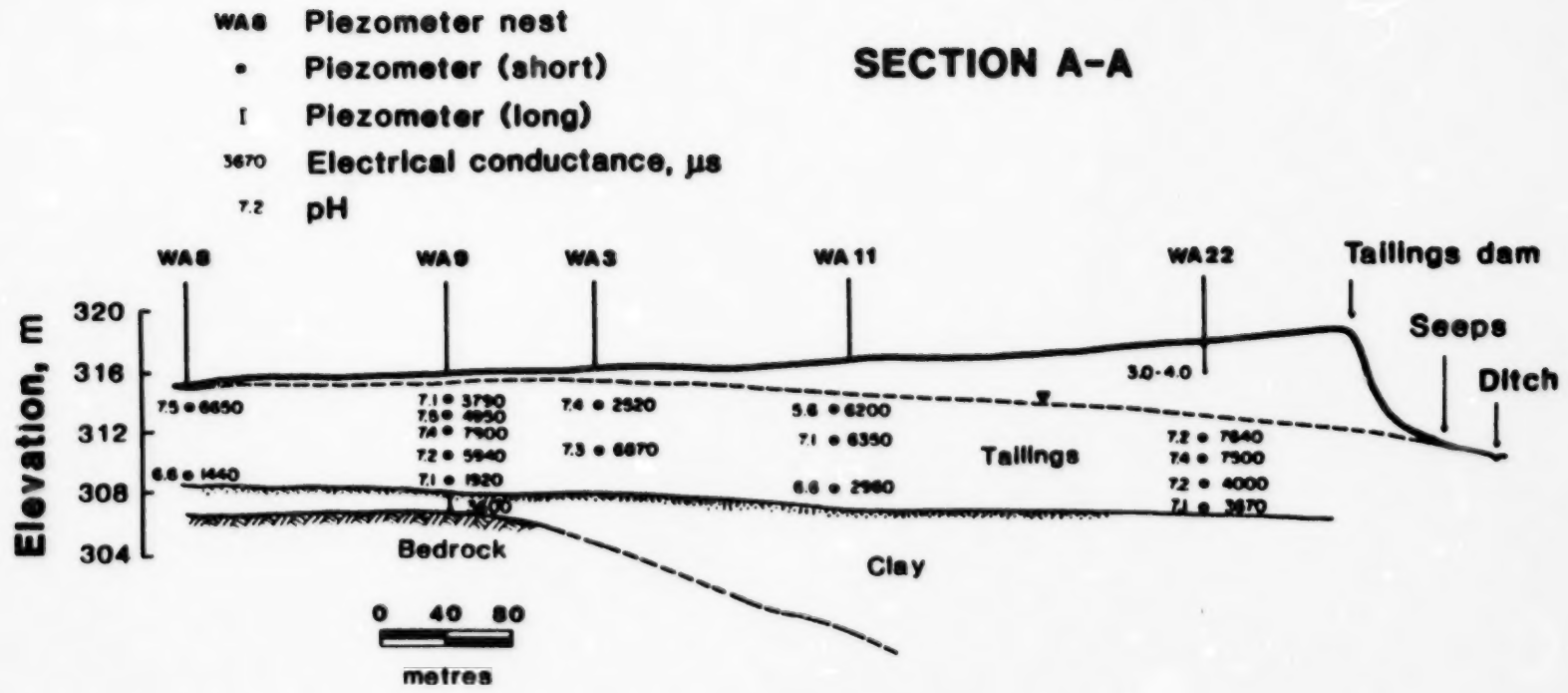


Figure 4 - pH and Electrical Conductance Along Section A-A

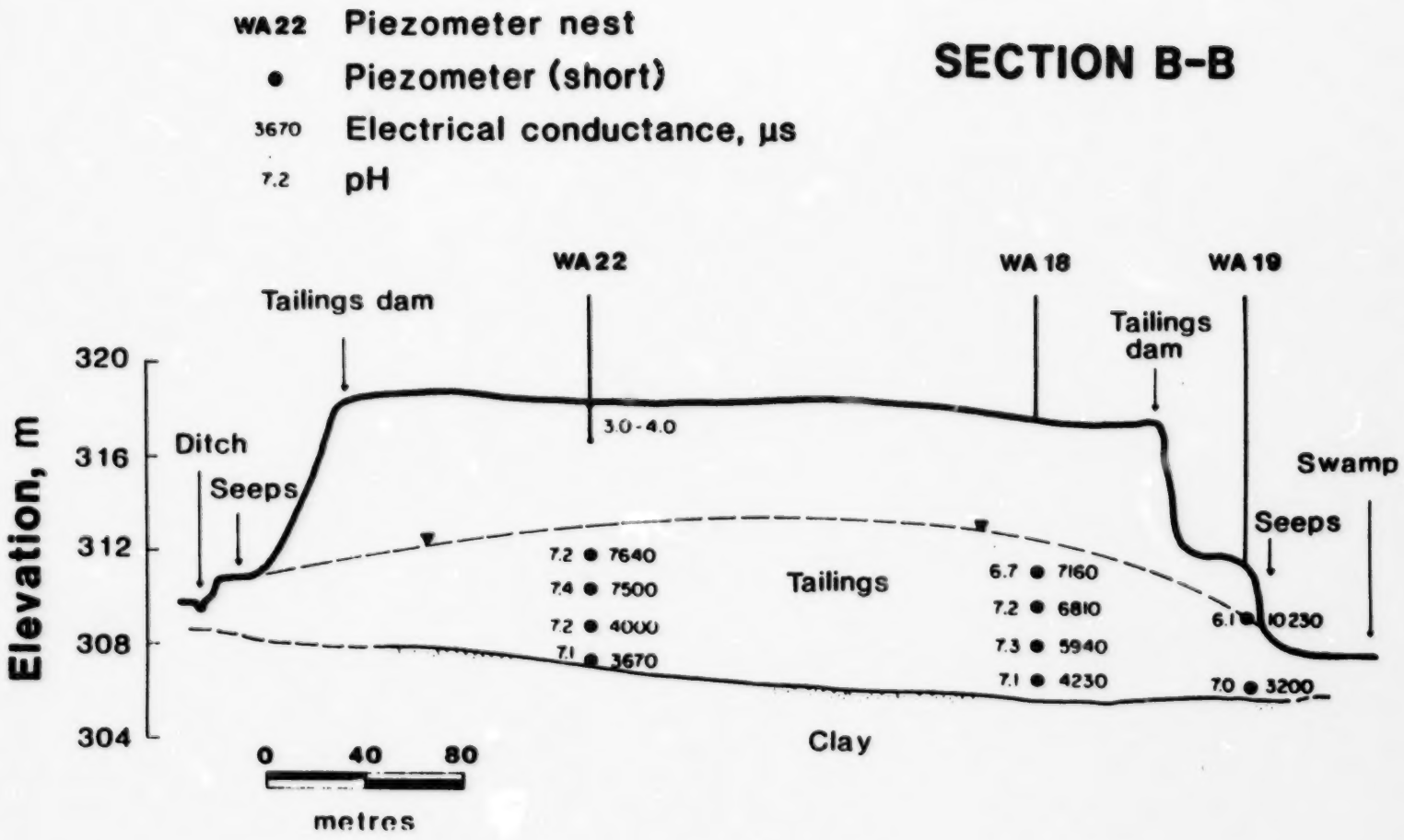


Figure 5 - pH and Electrical Conductance Along Section B-B

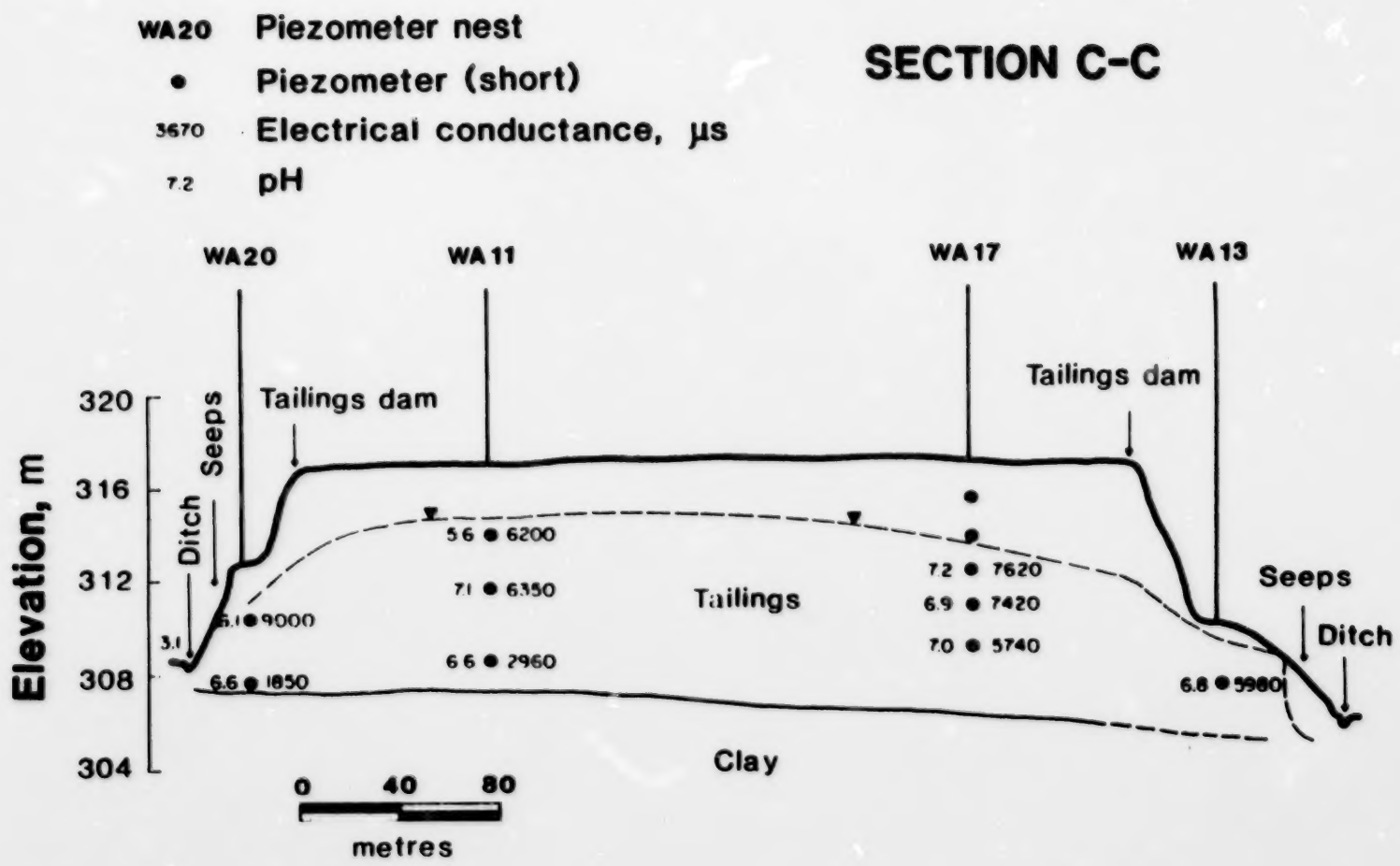


Figure 6 - pH and Electrical Conductance for Section C-C

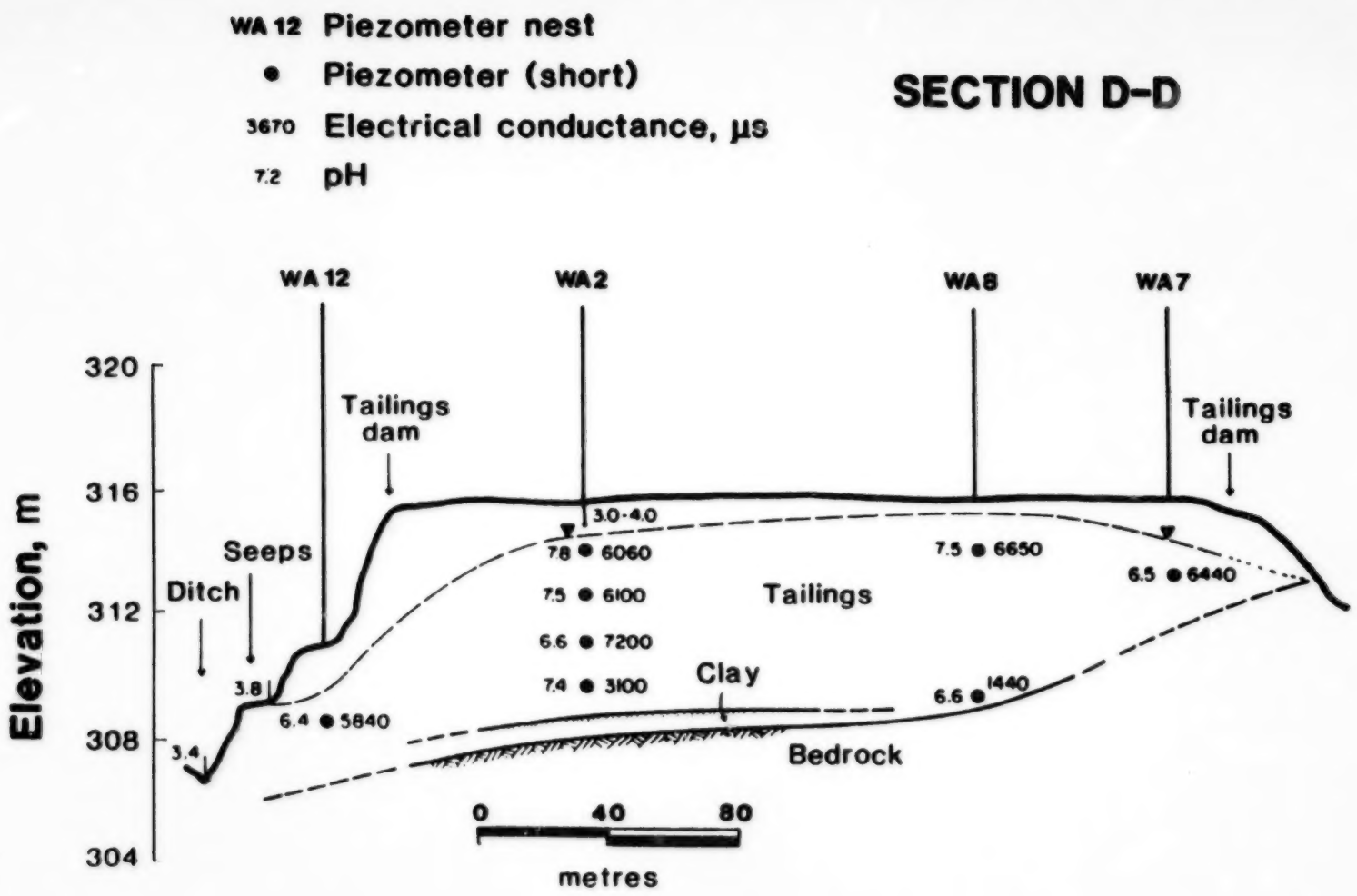


Figure 7 - pH and Electrical Conductance for Action D-D

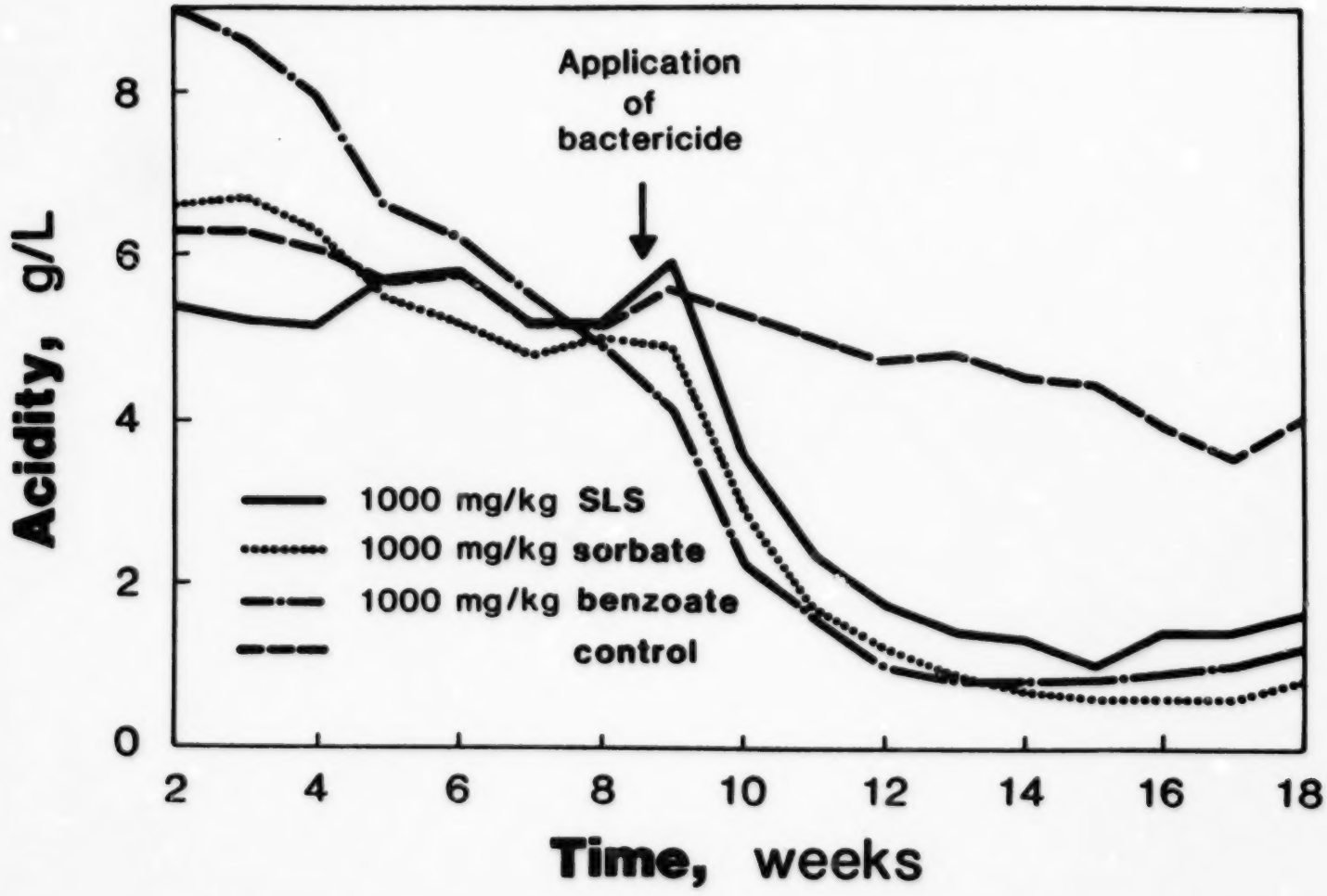


Figure 8 - Reduction of Acidity with Time for 1000 mg/kg Application Rate

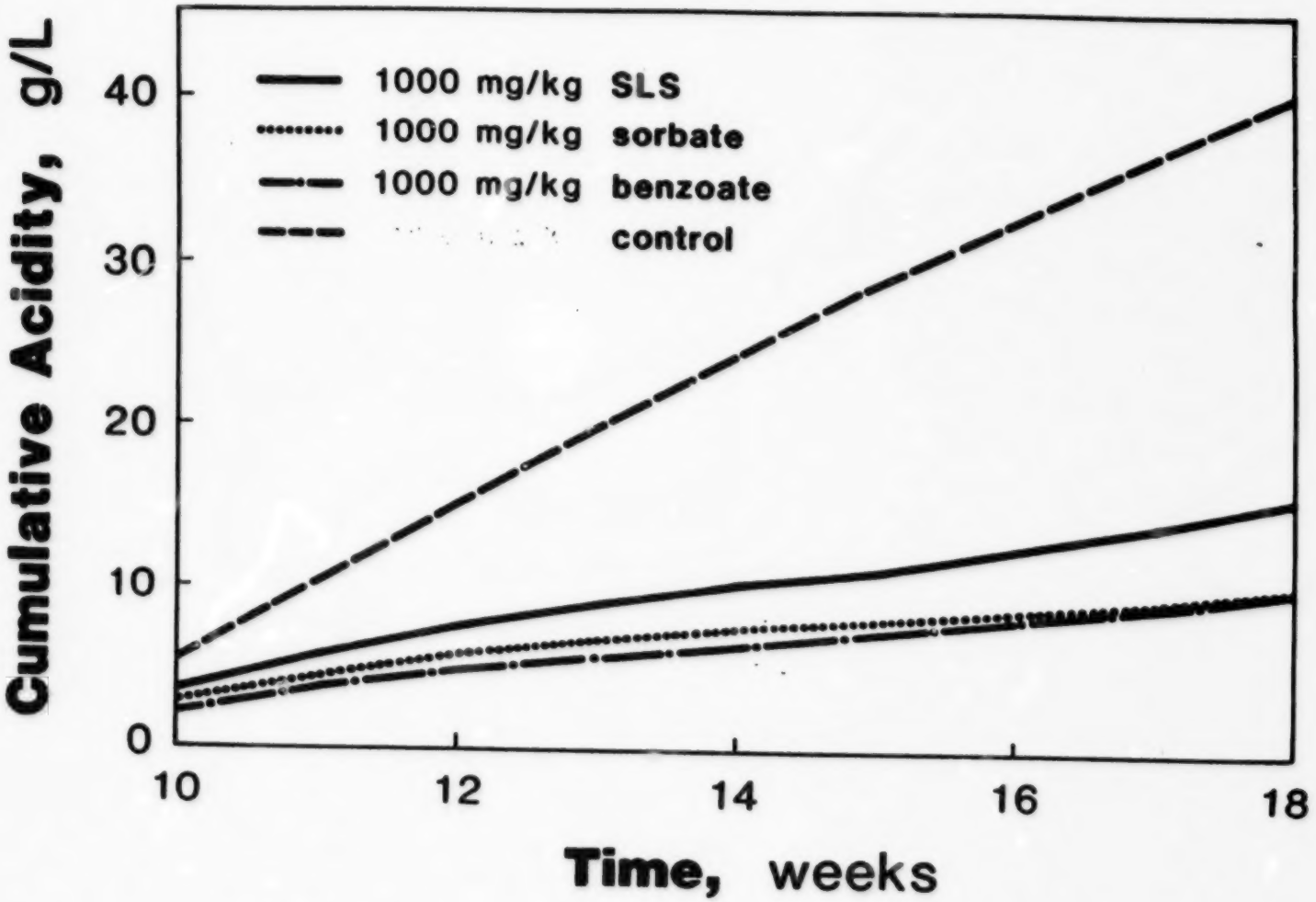


Figure 9 - Cummulative Acidity with Time for 1000 mg/kg Application Rate

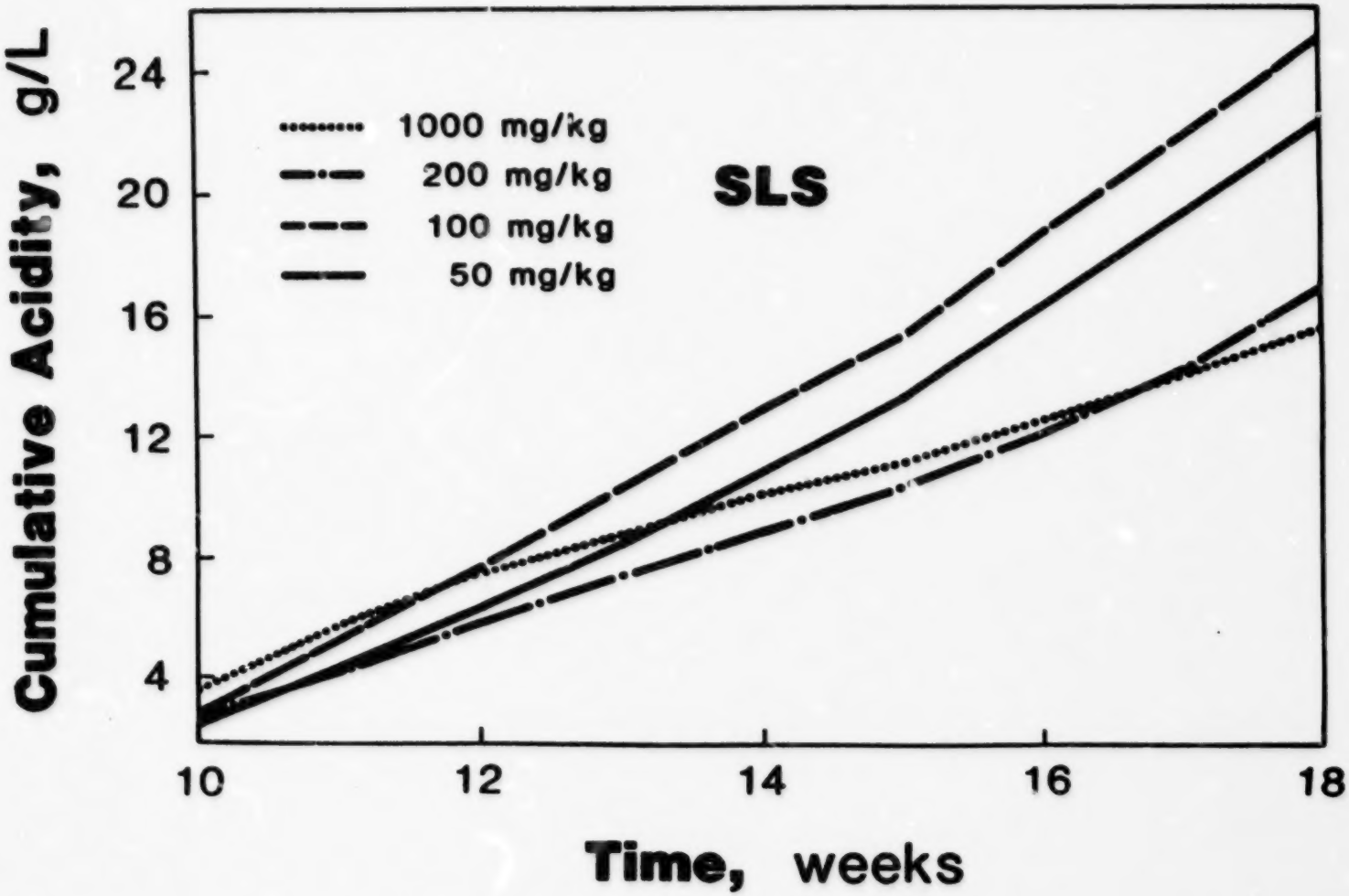


Figure 10 - Cumulative Acidity with Time for 50, 100, 200 and 1000 mg/kg SLS